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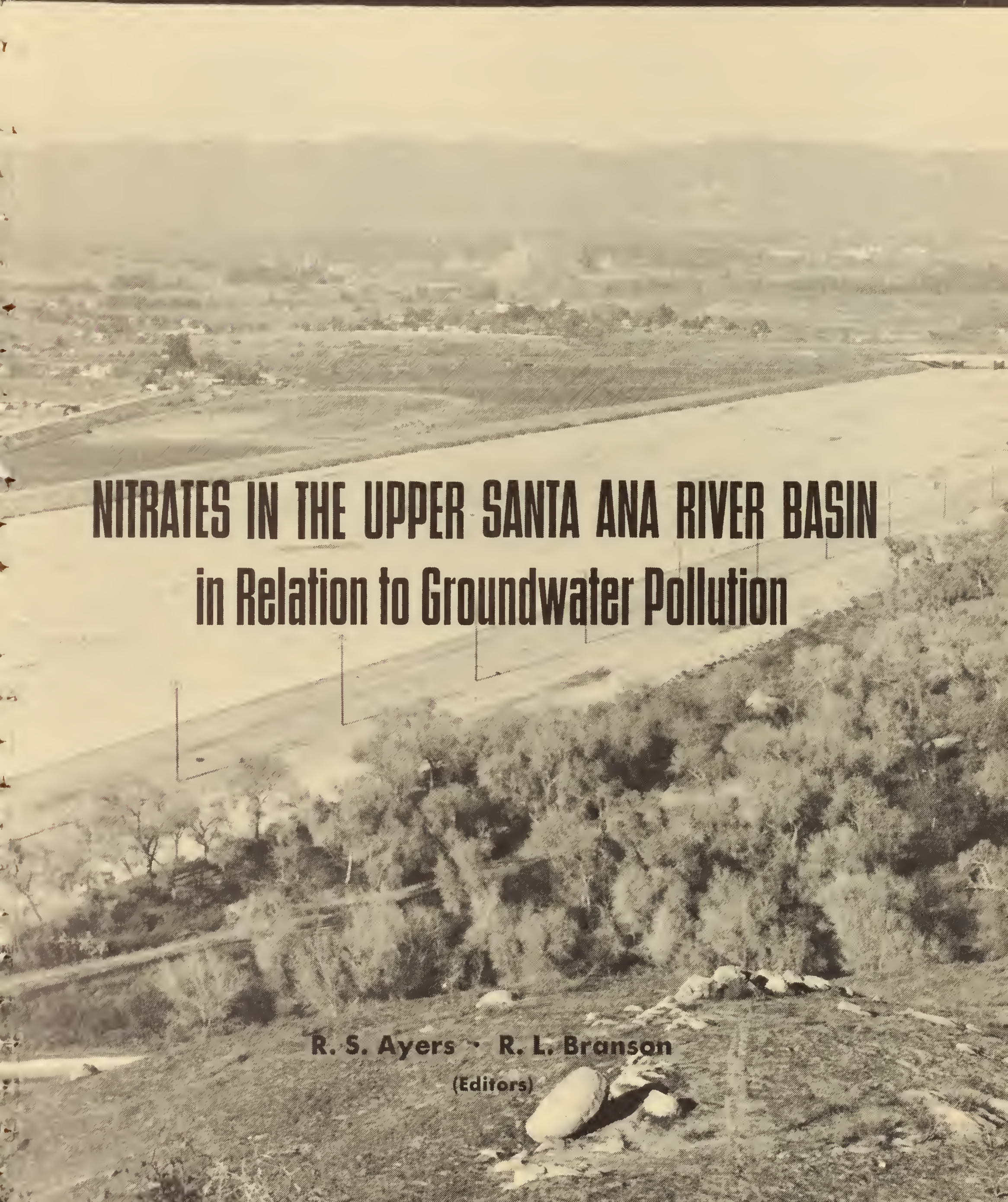

NITRATES IN THE UPPER SANTA ANA RIVER BASIN
in Relation to Groundwater Pollution

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(Editors)

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The extensive groundwater supplies in the Santa Ana Basin constitute a valuable resource which must be protected from excessive degradation if long-term beneficial use is to be realized. Nitrate in some of the Basin's well waters is already in excess of drinking-water standards of the U. S. Public Health Service.

At the request of the Santa Ana Watershed Planning Agency (SAWPA), the Kearney Foundation of the University of California made a 3-month study of the nitrate problem in the Basin. The study was restricted for the most part to the Upper Basin (above Prado Dam), where preliminary work indicated that nitrate degradation of waters was most serious. A multidisciplinary approach was used for analyzing problem areas of high nitrate concentrations in the groundwaters, determining the probable cause of each problem area (agricultural fertilizers, manure disposal, waste-water disposal, etc.), and developing recommendations for prevention of future problems of a similar nature in the watershed. University staff (from the Experiment Station and Agricultural Extension) involved in this study represented the fields of surface and groundwater hydrology, soil and water chemistry, soil microbiology, sanitary and agricultural engineering, water science, and plant science.

Specific objectives included: a review of available data in order to identify and quantify existing high nitrate concentrations in groundwater; a review of the history of land and water use, waste disposal, and other practices in each problem area to form judgments on causes of high nitrate concentrations; development of guidelines for rates of fertilization, water application, and animal waste disposal which will appreciably reduce the potential for nitrogen pollution of surface and groundwaters of the Basin consistent with reasonable levels of agricultural production; identification of areas of potential pollution related to nitrogen but not of primary concern in this study; and last but not least, identification of problems needing further study.

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NITRATES IN THE UPPER SANTA ANA RIVER BASIN IN RELATION TO GROUNDWATER POLLUTION[1]

INTRODUCTION

Nitrogen is an essential element for all biological life processes even though it is not one of the earth's more abundant elements. When nitrogen or its compounds are in limiting amounts, food and fiber production is reduced, animal and human health is impaired by protein deficiency, and decay of waste materials may be slowed. Conversely, excessive amounts of nitrogen and its compounds may be harmful to infants and livestock, may contribute to the eutrophication of surface water bodies, and may delay the ripening of certain fruits, vegetables, and other crops. Under an undisturbed virgin environment the cycle of synthesis, consumption, excretion, and decay of nitrogenous matter takes place diffusively but at roughly the point of origin, so that excesses and deficiencies of nitrogen are more or less balanced. Man disturbs this delicate balance by choosing to live in cities, and by concentrating livestock and dairy operations and producing and processing food and other products in localized areas. A concentrating effect results, with sewage, manure, other nitrogenous wastes, and fertilizers disposed or applied as point sources in such quantities as to overload nature's capacity to degrade and consume nitrate as fast as it is formed. The result is nitrate accumulation.

Global nitrogen geochemistry and distribution

Calvin (1956) estimates the earth to be 5 to 10 billion years old. About 4 billion years ago our atmosphere rose from gases emanated from the earth's interior. During this period of intense geologic activity gaseous nitrogen in the form of ammonia (NH_3), along with other gases, was emitted from fundamental rocks (Hutchinson, 1944). Then, 2 to 3 billion years ago, organic molecules were formed by nonbiological activities (Calvin, 1956) from, for example, electrical discharges and solar radiation. Amino acids and other complex nitrogen compounds were thus synthesized. These inorganic and organic nitrogen molecules accumulated randomly in the shallow seas, from which living organisms were systematically evolved some 1 to 2 billion years ago. This was the beginning of our biosphere. Green plants emitted oxygen through photosynthesis, and, as the atmosphere became oxygen-enriched, the reduced forms of nitrogen were oxidized to molecular nitrogen (N_2). The evolution of living organisms then gave rise to biochemical nitrogen transformations (Bartholomew and Clark, 1965). Plants, for instance, consumed simple inorganic nitrogen compounds and synthesized complex organic nitrogen compounds (proteins). Animals, in turn, consumed plant proteins to form animal proteins. At death, plant and animal proteins are decomposed to the more simple inorganic nitrogen forms by bacterial and fungal activities. Thus began the nitrogen cycle, and eventually our atmosphere attained the present level of 78.09 per cent nitrogen by volume, or 75.51 per cent nitrogen by weight (Hutchinson, 1954).

Table 1 gives an estimated geochemical distribution of nitrogen. These estimates indicate that the bulk of the nitrogen is tied up in the lithosphere (98.03 per cent)

[1] Submitted for publication December 30, 1971.

Table 1

GEOCHEMICAL DISTRIBUTION OF NITROGEN (AFTER BARTHOLOMEW AND CLARK 1965)

Distribution area	Total amount of nitrogen in each area*		Per cent of total nitrogen each area contains
	geograms	*tons*	
Atmosphere..	38.6480	0.425×10^{16}	1.96
Lithosphere..	1,934.0000	2.127×10^{17}	98.03
Biosphere....	0.0164	1.804×10^{11}	0.01

* Total amount of nitrogen in all areas equals 1,972.6644 geograms, or 2.170×10^{17} tons. One geogram = 10^{20} grams.

and in the atmosphere (1.96 per cent). The lithosphere (soil, substrata, rocks) contains 50 times as much nitrogen as the atmosphere on a geochemical scale. Although amounts of nitrogen present in the biosphere are comparatively quite insignificant, it is this insignificant fraction that supports life on earth.

Nitrogen pools in the Upper Santa Ana River Basin

Another perspective on nitrogen distribution is provided by the appraisal of the entire Upper Santa Ana River Basin shown in table 2, with the sources and sinks of nitrogen grouped arbitrarily into several nitrogen pools. (These pools may serve as either sources or sinks, but more often as both.) The mass given for nitrogen in these pools is an estimate based on the 1960 level of development and for the 356,000 acres of land overlying the water-bearing zone in the Upper Basin; it does not encompass the watershed or the nonwater-bearing zones. In making these estimates it was assumed that the soil zone represents the surface 6 feet beneath the land surface, and that the respective mean thicknesses of the unsaturated and saturated zones are 150 and 750 feet.

If we examine only the top 900 feet of the earth's crust and 356,000 acres of land surface in the Upper Basin, the relative distribution of nitrogen is quite different from that on a geochemical scale. Table 2 shows that the total mass of nitrogen in the Basin is nearly 1.3 billion tons, distributed as 96.66 per cent in the atmosphere, 3.08 per cent in the substrata, 0.2 per cent in the soil, and the remainder in other nitrogen pools. Table 2 footnotes give the rationale for estimation of these masses of nitrogen.

The atmospheric nitrogen pool is a major nitrogen reservoir containing about 78 per cent nitrogen by volume of air, or about 35,000 tons nitrogen per acre of land surface (Bartholomew and Clark, 1965). Nitrogen in the atmosphere exists primarily as molecular nitrogen (N_2), which is an inert gas. Nitrogen losses from the atmosphere are more or less balanced by gains in gaseous nitrogen

Table 2

MASS OF NITROGEN IN THE UPPER SANTA ANA RIVER BASIN (BASED ON 1960 LEVEL OF DEVELOPMENT; 356,000 ACRES OVERLYING GROUNDWATER RESERVOIR; 960-FOOT-THICK WATER-BEARING SEDIMENTS)

Location of nitrogen pools in basin	Tons of nitrogen in each pool	Per cent of total nitrogen in each pool
Atmosphere*......	1.246×10^{9}	96.66
Land surface†.....	2.87×10^{4}	0.002
Soil‡..............	2.85×10^{6}	0.22
Substrata§........	3.97×10^{7}	3.08
Surface water‖....	5.94×10^{3}	0.0005
Groundwater¶.....	5.79×10^{4}	0.004
Total nitrogen in all pools.........	1.289×10^{9}	—

* 78.09% nitrogen by volume; 35,000 tons nitrogen per acre; 3.56 x 10^5 acres.

† Vegetation: 6.50 tons dry matter per acre per year; 1.5% nitrogen; 1.62 x 10^5 acres arable land, 1.5-year growth (23.814 x 10^3 tons).
Man: 70 g protein per capita; 16% nitrogen; 630,000 population (3.528×10^3 tons).
Poultry: 6.4×10^6 chickens; 3 lb per chicken; 3% nitrogen (0.288×10^3 tons).
Cattle: 70,122 head; 1,000 lb per head; 3% nitrogen (1.053×10^3 tons).

‡ 0.07% nitrogen, bulk density of 1.4 g per cc; 6 ft deep; 3.56 x 10^5 acres.

§ 46 g nitrogen per ton, bulk density of 1.8 g per cc; 900 ft deep; 3.56 x 10^5 acres.

‖ Pumped: 540,170 acre-feet water; 30 ppm NO_3^- (4.995 x 10^3 tons).
Streamflow, imported: 147,630 acre-feet water; 1 ppm nitrogen (0.201 x 10^3 tons).
Agricultural return flow: 174,460 acre-feet water; 3 ppm nitrogen (0.712×10^3 tons).
Urban irrig. return flow: 15,230 acre-feet water; 0.4 lb nitrogen per acre-inch (0.037×10^3 tons).

¶ Saturated zone: 15.716×10^6 acre-feet water; 10 ppm NO_3 (4.916 x 10^4 tons).
Unsaturated zone: 0.715 x 10^6 acre-feet water; 40 ppm NO_3 (8.752×10^3 tons).

from soil and land surface. However, in areas of high population density and industrial activities gains generally exceed losses so that the atmosphere becomes polluted with oxides of nitrogen and other emissions (smog components). Air currents presumably export to other basins much of the nitrogen emitted, but some is returned to the land surface.

According to Odum (1959), dry-matter productivity of various ecosystems ranges from less than 0.5 grams dry matter per meter per day (in deserts) to 1 gram (in grasslands and some agriculture) to as high as 10 grams (in intensively cultivated lands). It was assumed that the Upper Basin produced 4 grams per square meter per day (6.50 tons of dry matter per acre-year) for 162,000 acres of arable land, and that the dry matter contained 1.5 per cent nitrogen. It was further assumed that the vegetative cover averaged 1.5 years of growth. The protein content of children, women, and men varies between 40 and 100 grams (USDA Food Yearbook, 1959). By assuming 70 grams protein per capita, 16 per cent nitrogen in protein, and a population of 630,000 (WRE, 1969), one can estimate for the Upper Basin the mass of nitrogen in humans (second footnote in table 2). Nitrogen estimates for the poultry and cattle were derived from population figures, average weight of animals, and 3 per cent nitrogen by weight (Chang and Fairbank, 1971). Needless to say, there are other sources of nitrogen on the land surface, but estimates are difficult to obtain. Some of the nitrogen-containing matter is imported to or exported from (or both) to other basins.

On the land and in the soil zone, most nitrogen is tied up in the organic form (plant and animal proteins or their transitory decay products) with smaller fractions in inorganic forms. Except in the atmospheric nitrogen pool, organic and inorganic forms of nitrogen tend to degrade to nitrate under natural biological processes. The nitrate is then recycled as it is consumed by plants and microbes. If the consumption rate is less than the rate of emission, nitrates will accumulate. Nitrates are stable but they are completely water-soluble and thus move with water, so that one finds nitrate as the principal nitrogen compound in surface and groundwater nitrogen pools.

The largest nitrogen pools next to those in the atmosphere are found in the soil and substrata zones. Nitrogen in the soil zone ranges from about 0.02 to 0.5 per cent of total nitrogen by weight, or about 800 to 20,000 pounds per acre-foot of surface soil (Lyon *et al.*, 1952). For the Upper Basin it was assumed that soil nitrogen is 0.07 per cent, bulk density is 1.4 grams per cubic centimeter, soil depth is 6 feet, and the surface area is 356,000 acres. Much of this nitrogen is in the organic form, and is not readily available as fertilizer nutrient to plants, or readily leached out by percolating water. Sediments in the substratum zone are derived chiefly from igneous rocks, which contain about 46 grams nitrogen per ton (Feth, 1966). By assuming a bulk density of about 1.8 grams per cubic centimeter, a depth of 900 feet and a surface area of 356,000 acres, the mass of nitrogen in the substrata nitrogen pool was estimated. Nitrogen in substratum materials is not readily leached or released, because it is tightly fixed in the mineral or rock as ammonium ion (NH_4^+). Thus, even though nitrogen pools in the soil and substrata contain the larger fractions of nitrogen present in the biosphere, they do not figure significantly in over-all transfer of nitrogen in the environment.

Precipitation, natural streamflow, and applied waters that infiltrate the land surface and pass through the soil zone carry the mobile forms of nitrogen (nitrate [NO_3^-]; nitrite [NO_2^-]; and to some extent ammonia [NH_4^+]) and are leached into the substrata. In the unsaturated zone (zone of aeration), water generally percolates deeply to the water table and recharges groundwater reservoirs. Depending on profile stratification in the basin, some percolating water may become perched and move horizontally as subsurface flow. For the Upper Santa Ana Basin, nitrates in subsurface and groundwater eventually reappear with rising waters at Prado Dam and a few other points in the Santa Ana River. Travel time is, however, exceedingly long because groundwater flow rates range from less than 5 feet per year to about 20 feet per year

(Todd, 1959). Because a major source of water supply in this basin is groundwater, nitrates in the groundwater nitrogen pool are to some extent recycled back to the land surface.

Background nitrate concentrations in surface and groundwaters are reported to be about 20 ppm nitrate or less (Feth, 1966). The estimated mass of nitrogen in surface and groundwaters was developed from hydrologic data reported by Water Resources Engineers, Inc. (WRE) (1970) and California Department of Water Resources (DWR) Bulletins 71, 71–64, and 104–3 (1960, 1966, 1970); estimates on nitrogen concentration are given in the footnotes of table 2. It was estimated that streamflow and imported water contained about 1 ppm nitrogen (DWR Bul. 65–61, 1964), agricultural return flow about 3 ppm nitrogen (Sylvester, 1961), and urban irrigation return flow about 0.4 pounds nitrogen per acre-inch (Kaiser Engineers, 1969). For saturated and unsaturated zones (comprising the groundwater nitrogen pool), it was estimated that the respective nitrate concentrations were 10 and 40 ppm. Even though the largest nitrogen sources are geochemical in origin (atmosphere, soil, and substrata), they are immobile, inactive, or in various stages of decay, so that it is the man-induced activities which generally contribute to the presence of nitrates in excess of background levels. Man's activities are manifested by his intense and diverse use of land, by waste treatment and disposal practices, and by management of water. Water is the principal carrier of nitrates to the groundwater.

Nitrogen standards for water

Although nitrogen pollution of waters may result from organic and inorganic forms, and from dissolved and particulate forms, it is the nitrate form which has been commonly monitored and accepted as a pollution parameter. The rationale has been that nitrate is one of the end products of biological oxidation and is the traditional public-health measure of pollution. The hazard of high nitrate to infants and livestock is illustrated by a disease known as methemoglobinemia or nitrate cyanosis which is caused by nitrite formed from reduction of nitrate in the intestinal tract. Nitrite enters the blood stream and combines with hemoglobin to form methemoglobin, thus reducing the blood's capacity to transport oxygen. This reduction to nitrite occurs in infants because their gastric juices are more nearly neutral than those of adults which have an acidic balance (Fair *et al.*, 1968). Methemoglobinemia may also result from congenital heart diseases and inhalation or ingestion of certain kinds of chemicals in drugs (Walton, 1951).

Similar nitrate-nitrite poisoning effects have been noted in ruminants (such as cattle) at concentration levels in waters exceeding 2,000 ppm nitrate, but nitrate poisoning results more commonly from the consumption of large amounts of feeds or plants containing high levels of nitrate (Tucker, *et al.*, 1961). Tucker lists over 50 plants that have been involved in nitrate poisoning, or which have been reported as capable of accumulating appreciable amounts of nitrate. These plants, ranging from weeds to shrubs, vegetables, and other crop plants, are considered potentially toxic if they contain more nitrogen than about 2,000 ppm (green weight) in the form of nitrate.

The U. S. Public Health Service in its 1962 *Drinking-Water Standards* recommends a limit of 45 ppm nitrate or 10 ppm nitrogen (McKee and Wolf, 1963). At this concentration, the public is to be warned of the potential dangers of using the water for infant feeding. Prior to 1962, nitrate standards were not used for drinking waters. Since well waters with nitrates exceeding this standard are widespread in California without being known to produce methemoglobinemia (DWR Bul. 143–6, 1968), California has a recommended limit of 45 ppm and a mandatory limit of 90 ppm nitrate. McKee and Wolf (1963) reported that many well waters containing over 500 ppm of nitrate have never been linked with reported cases, but most cases of this disease (occurring elsewhere in the U. S. and Europe) have been associated with waters containing more than 50 ppm nitrate. Moreover, most reported cases involve use of water from dug wells or shallow wells

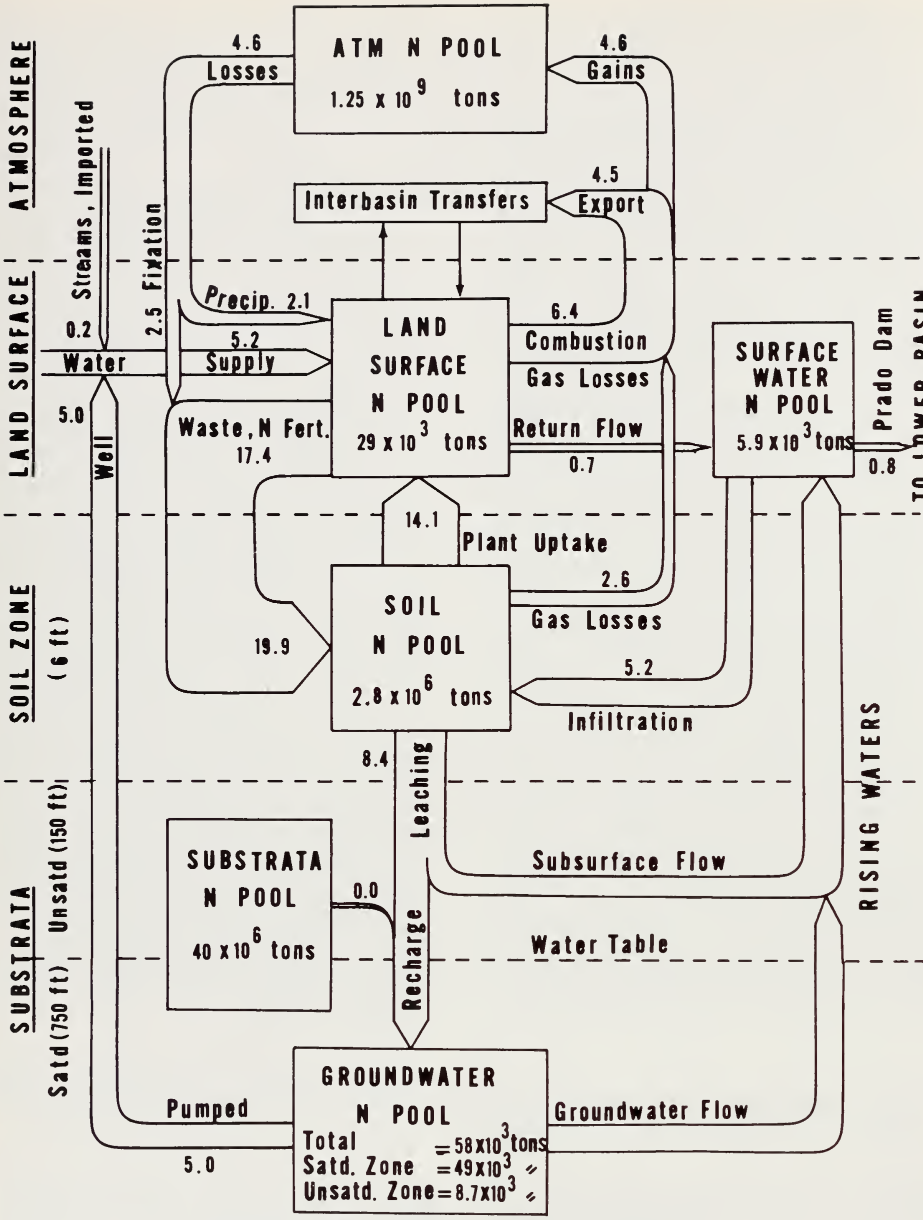
near barnyard waste-disposal sites. Excess nitrates have been known to cause diarrhea when one liter of water containing 500 ppm nitrate was consumed. Apparently there is considerable uncertainty over the scientific validity of these nitrogen standards. The National Technical Advisory Committee for public water supplies recently recommended for surface waters permissible levels for ammonia of 0.5 ppm nitrogen and, for nitrate plus nitrite, 10 ppm nitrogen (Federal Water Pollution Control Administration [FWPCA] 1968). No standards for well waters were reported by the Committee.

Nitrates in water may be undesirable or harmful for certain industries such as brewing, or for other fermentation processes or food processing. Recommended limits are generally set at 15 to 30 ppm nitrate (McKee and Wolf, 1963). Nitrates in irrigation waters may be considered beneficial because of their fertilizer value: for example, a 4-inch application of water containing 50 ppm nitrate is equivalent to a rate of 10 pounds of nitrogen per acre. For certain crops, however (e.g., sugar beets, grapes), a continuous supply of nitrogen is undesirable because it adversely affects crop maturation. The ability of water bodies to produce aquatic plants and animals is affected by nutrient supply. Insufficient sources of nitrogen often limit the growth of algae and other planktons which are a food source for plant-eating aquatic organisms (zooplanktons), which in turn are themselves consumed by higher forms of predators. This is repeated on up the food chain to fish. If other environmental factors are favorable, the more abundant the nutrient supply (N, P, C, etc.) the more dense the aquatic vegetation. It is only when aquatic plants become too dense and/or interfere with the beneficial uses of water that eutrophication is considered detrimental (FWPCA, 1968). The critical level, above which nitrogen contributes to detrimental algal bloom and to rank growth of aquatic weeds, is difficult to assess because many factors are involved. It has been suggested, for example, that a critical level for Wisconsin lakes is about 0.3 ppm inorganic nitrogen (State Water Quality Control Board [SWQCB] Pub. No. **34**, 1967), but this level should not be extrapolated to all California bodies of water because each stream, lake, or estuary has individual characteristics. For example, algal blooms have not resulted from 1 ppm nitrogen in the Sacramento River or from 3 ppm nitrogen in the eastern Sacramento-San Joaquin Delta (Kaiser Engineers, 1969). However, factors other than nitrogen are presumed to be limiting to growth of algae; these may include clarity or turbidity of the water body (lack of sunlight energy source), absence of certain essential trace elements, presence of one or more toxic elements, or low or insufficient levels of other normal essential nutrients such as phosphorus or carbon. Algae require both sunlight and plant nutrients.

THE NITROGEN PROBLEM IN BASIN-WIDE SYSTEMS

Figure 1 presents an over-all appraisal of nitrogen pools and fluxes for the Upper Santa Ana River Basin. Along the left margin of this flow sheet are the surface and subsurface subsystems or zones. For each of these subsystems there are one or more pools (table 2) represented in figure 1 by rectangular boxes. The arrows going from one pool to another pool represent the various transport pathways. The numbers in and around these arrows are the fluxes (transfer rates) of nitrogen in thousands of tons nitrogen per year. These fluxes were estimated by evaluating (among many others) the various mechanisms or processes in the nitrogen cycle, the nitrogen contents of natural and man-made substances, the land use, and the hydrologic data. Sources making up these fluxes are shown in table 3, and the fate of the nitrogen loadings in table 4.

The atmosphere in this basin loses about 4,628 tons of nitrogen per year. Of this 2,136 tons return to the land in rain,



NITROGEN POOLS AND FLUXES

Fig. 1. Nitrogen pools and fluxes in the 356,000-acre upper Santa Ana Basin based upon the 1960 level of development. The mass of nitrogen in the pools is in tons of nitrogen; numbers near the arrows represent the flux of nitrogen between pools in thousands of tons of nitrogen per year.

TABLE 3

ESTIMATED SOURCES AND ANNUAL LOADING RATE OF NITROGEN*

Sources of N or NO_3 distributed	Estimated rates of N or NO_3 distributed on soil, water, people, livestock, or as effluent	Loading rate (tons per year)
Precipitation (rain, fallout).......	8 lb. N per acre annually on 356,000 acres of soil	1,424
Sorption (ammonia)..............	4 lb. N per acre annually on 356,000 acres of soil	712
Symbiotic N fixation.............	10 lb. N per acre annually on 356,000 acres of soil	1,780
Nonsymbiotic N fixation.........	4 lb. N per acre annually on 356,000 acres of soil	712
Combustion......................	0.041 lb. N per person per day from 630,000 people	4,741
Municipal waste load.............	30 ppm N effluent on 83,700 acre-feet of soil	3,916
Industrial waste load.............	10 ppm N effluent on 5,930 acre-feet of soil	81
Manures (dairies, feedlots)........	130 lb. N per head per year from 70,122 cattle	4,558
Fertilizers........................	50 lb. N per acre per year from 356,000 acres	8,448
Prado Dam outfall...............	11.3 ppm NO_3 in 48,840 acre-feet of water	751

* Amounts of nitrogen measured in the surface waters of the basin stemming from various sources are found in the fifth footnote of table 2.

dry fallout, and sorption of ammonia, and the remainder is fixed in the soil by symbiotic and nonsymbiotic fixation. These losses are balanced by gains of 4,339 tons of nitrogen per year in gaseous nitrogen as ammonia volatilization (1,705 tons of nitrogen per year) from applications of manures and anhydrous ammonia on the land surface and as molecular nitrogen or oxides (2,634 tons nitrogen per year) from denitrification in the soil zone. An additional 4,741 tons of nitrogen per year is emitted by motor vehicles, boilers, incinerators, etc.—atmospheric gains from the land surface thus amount to 6,446 tons per year. The total atmospheric gains from volatilization, denitrification, and combustion are 9,080 tons nitrogen per year. If we assume that losses should equal gains, then 4,452 tons of nitrogen per year are exported.

In addition to bulk precipitation and sorption, the land surface receives about 5,196 tons nitrogen per year (on the 1960 basis) in the water supply, which comes from 201 tons nitrogen per year from streamflow and imported water, and 4,995 tons nitrogen per year from pumped groundwaters. Return-flow waters from urban and agricultural irrigations amount to 738 tons nitrogen per year. About 751 tons nitrogen was present in the 1960 outflow at Prado Dam. On the land surface, 3,916 tons nitrogen per year was produced in the form of municipal sewage and solid wastes, 81 tons nitrogen per year from industrial sources, 4,558 tons nitrogen per year in manures from feedlot

TABLE 4

ESTIMATED FATE OF NITROGEN LOADINGS

N sources	Volatile losses	Denitrification losses	Plant uptake	Potential leaching, accumulation, or later plant uptake
	Per cent of total tons N per year			
Municipal...............	—	10% (392 tons)	10% (392 tons)	80% (3,132 tons)
Industrial...............	—	—	—	100% (81 tons)
Manures................	30% (1,367 tons)	10% (456 tons)	40% (1,823 tons)	20% (912 tons)
Fertilizers..............	4% (338 tons)	15% (1,267 tons)	60% (5,069 tons)	21% (1,774 tons)
Water..................	—	10% (519 tons)	60% (3,116 tons)	30% (1,558 tons)
Fixed N.................	—	—	80% (1,994 tons)	20% (498 tons)
Precipitation............	—	—	80% (1,709 tons)	20% (427 tons)
Total tons N per year...	1,705	2,634	14,103	8,382

and dairy cattle, and 8,448 tons nitrogen per year from chemical nitrogen fertilizer applied. Manures and ammoniacal fertilizers applied on the land surface are subject to volatile losses, so that 3,191 tons nitrogen per year from manure and 8,110 tons nitrogen per year from fertilizer actually enter into the soil zone. The total load of nitrogen from the land surface (including precipitation and sorption) transferred to soil is estimated as 17,434 tons nitrogen per year. When 2,492 tons nitrogen per year of fixed nitrogen is added to this, the soil nitrogen pool receives 19,926 tons nitrogen per year plus the 5,194 tons nitrogen per year from the water supply, for a grand total flux of 25,120 tons nitrogen per year.

The soil, in turn, loses about 2,634 tons nitrogen per year to the atmosphere by denitrification and about 14,103 tons nitrogen per year to plant uptake, leaving 8,383 tons nitrogen per year potentially available for leaching to the substrata, accumulation in the soil, and/or plant uptake in succeeding years. Assuming 1.5 years of growth and yearly plant uptake as 14,103 tons nitrogen, the mass of nitrogen in land surface vegetation is 21,155 tons, compared with 23,814 tons estimated by another criterion (second footnote, table 2).

LOCATIONS OF HIGH NITRATE CONCENTRATIONS IN GROUNDWATER

The general nitrate distribution patterns discussed and mapped by Water Resources Engineers, Inc. (1970) have been confirmed by the present task group, whose main effort was centered on areas shown to be highest in nitrates on the 1968 map: Bunker Hill Sub-Basin (general area from Redlands to Norton Air Force Base); Middle Chino Sub-Basin (centering on the Laird community); and, to a lesser extent, the Riverside-Arlington Sub-Basin and the East Pomona area of the Upper Chino Sub-Basin. Figure 2 shows location of these areas of highest nitrate concentration.

Bunker Hill Sub-Basin: Redlands to Norton Air Force Base

1930–1940 nitrate situation. Early (1919–1937) water analyses on six wells in the area confirm that nitrates were low from 1930 to 1940 and earlier. Nitrate concentrations in these well waters ranged from 2 to 22 ppm of NO_3^-. Figure 3 shows locations of the wells and their nitrate concentrations with symbols indicating concentration ranges of 0 to 20 and 20 to 45 ppm of NO_3^-.

1950 nitrate situation. By 1950, many well waters had nitrate contents above 90 ppm. Sixty-two wells in the Bunker Hill study area (fig. 4) were sampled from 1948 to 1952 by various agencies, and nitrates above 90 ppm were present in 13 of them. Eleven of these wells of highest nitrate content lie close together in the area extending southeastward from California Avenue at the south bluff of the Santa Ana River bed to about Texas and San Bernardino Avenues, an area roughly 2.5 miles long by 0.5 mile wide. Away from this central high-nitrate area the nitrate concentrations decrease.

1958–1962 nitrate situation. Nitrates remained high in 1958–62 (fig. 5) but only 31 water analyses were available (as compared with 62 analyses for the 1950 period). These 31 analyses show a total of five wells above 90 ppm nitrate; three of these lie within the previously described 1950 high-nitrate area. Since many wells sampled within the central area in 1950 were not resampled in 1960, the true nitrate status of the central portion is not known. From 1950 to 1960, the high-nitrate area appears to have extended to the east but narrowed or withdrawn from the southwest, still trending in a NW–SE direction, and stretching roughly from the Redlands to Norton Air Force Base.

1965–1968 nitrate situation. Nitrate levels were generally lower in 1968 than

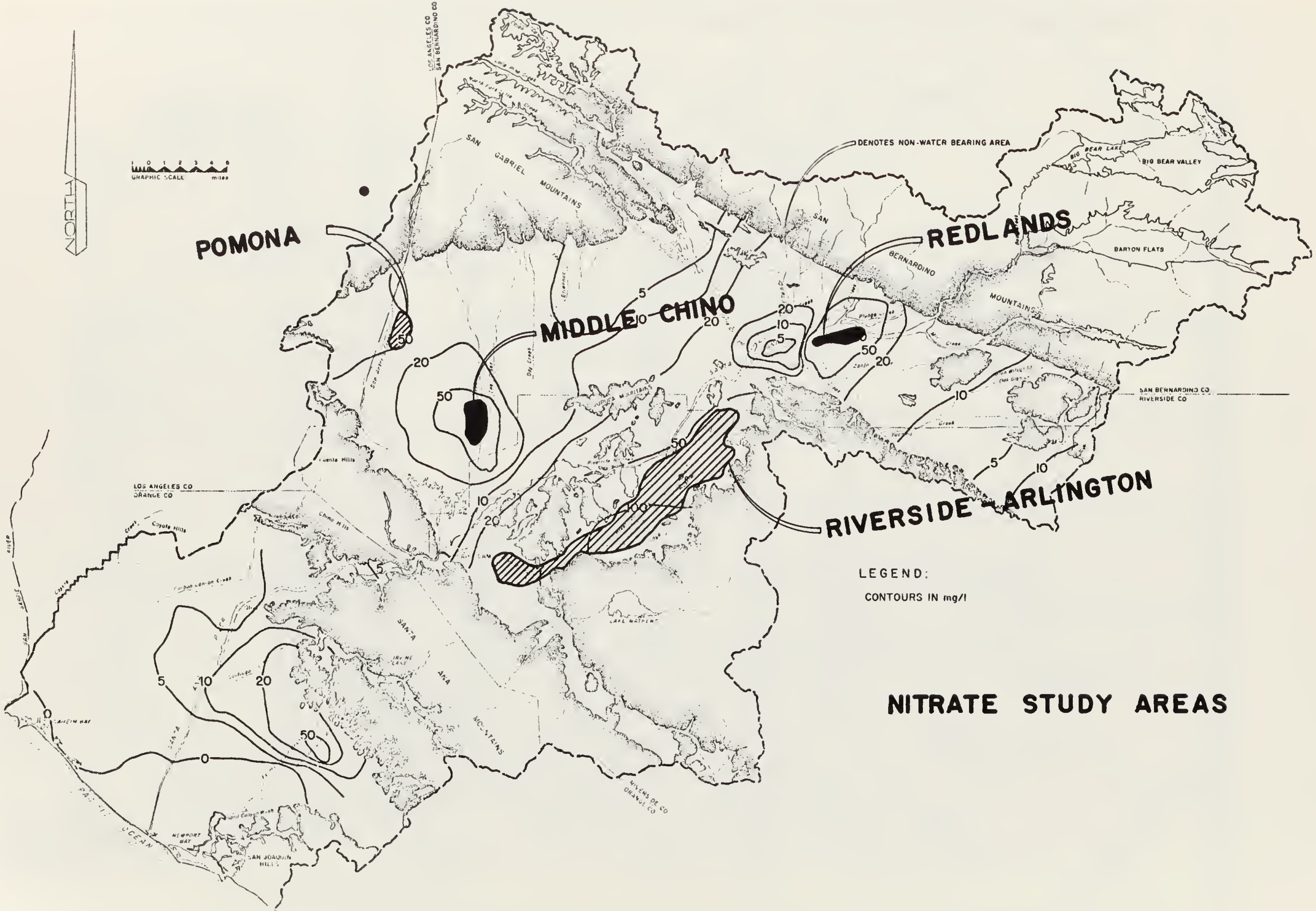


Fig. 2. Map of the Santa Ana Basin showing locations of areas of high nitrate concentration. (Courtesy Water Resources Engineers, Inc.)

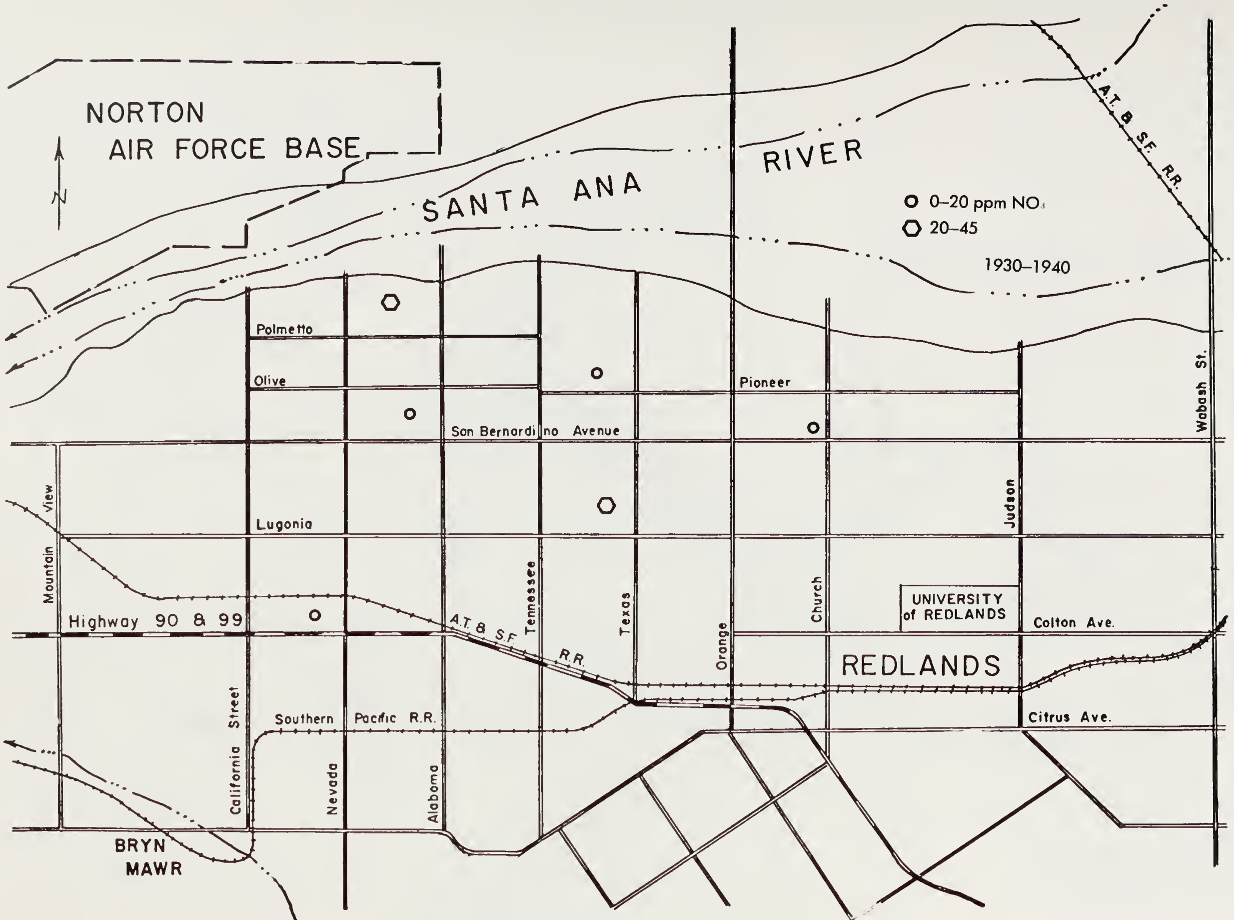


Fig. 3. Map of the Bunker Hill Sub-Basin showing nitrate concentrations of well waters between 1930 and 1940.

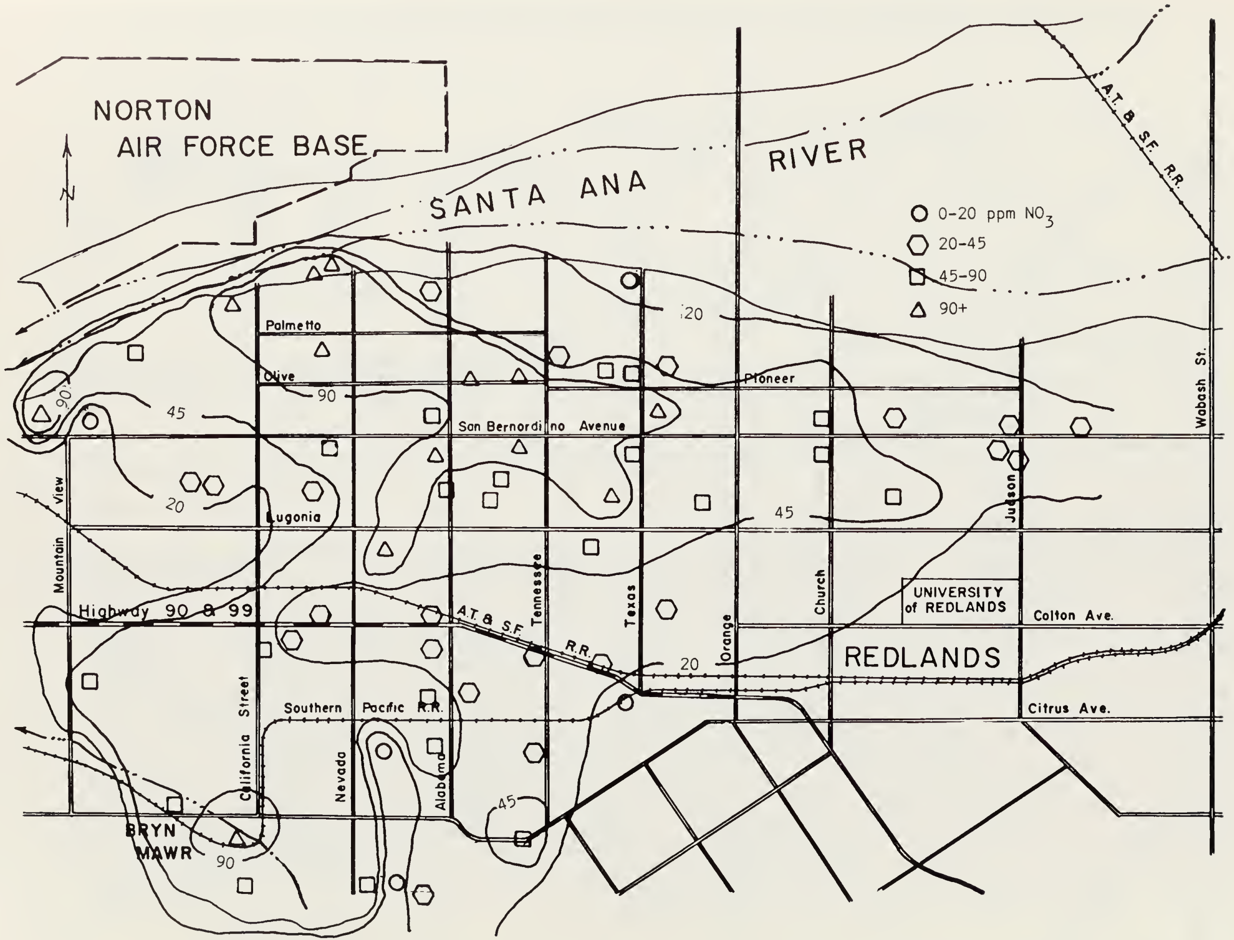


Fig. 4. Map of the Bunker Hill Sub-Basin showing nitrate concentrations of well waters in 1950.

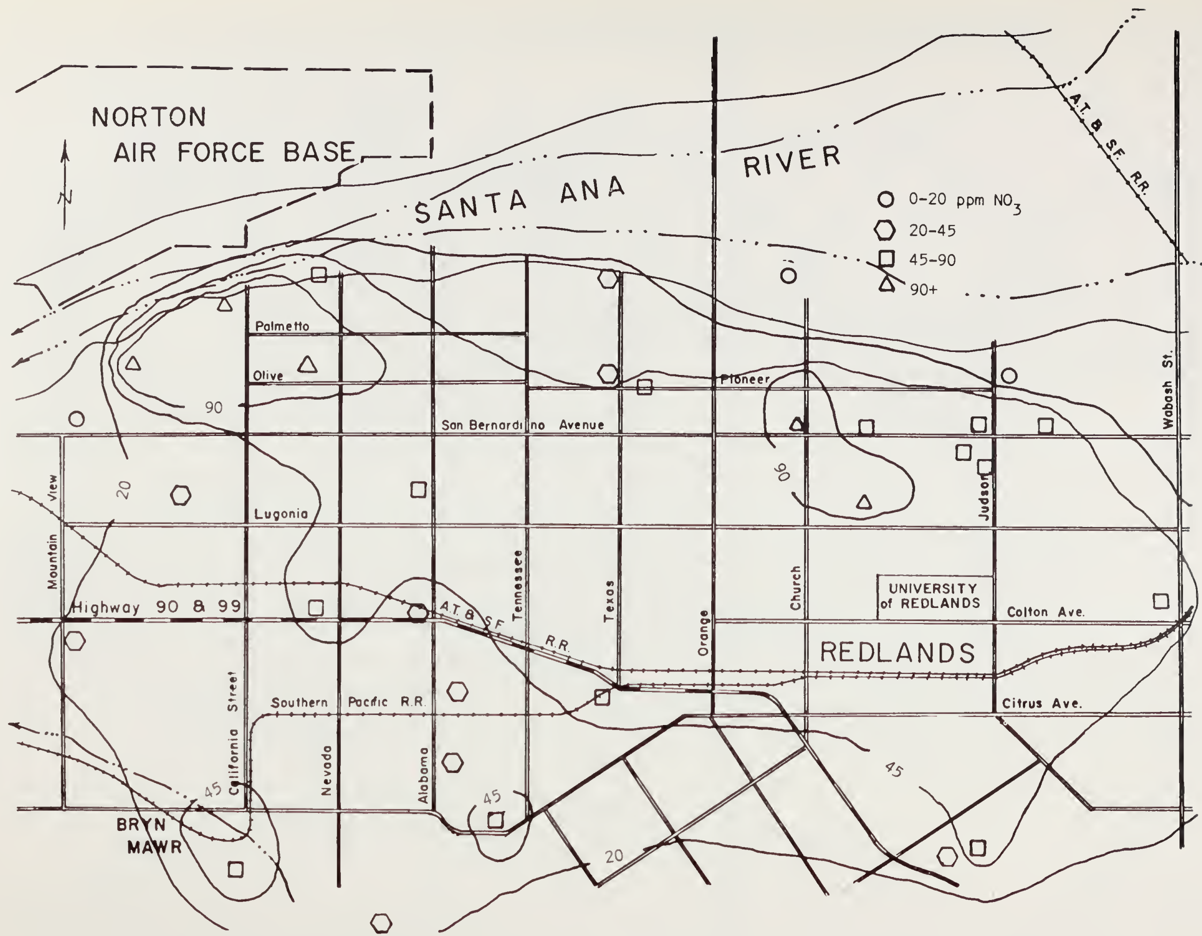


Fig. 5. Map of the Bunker Hill Sub-Basin showing nitrate concentrations of well waters between 1958 and 1962.

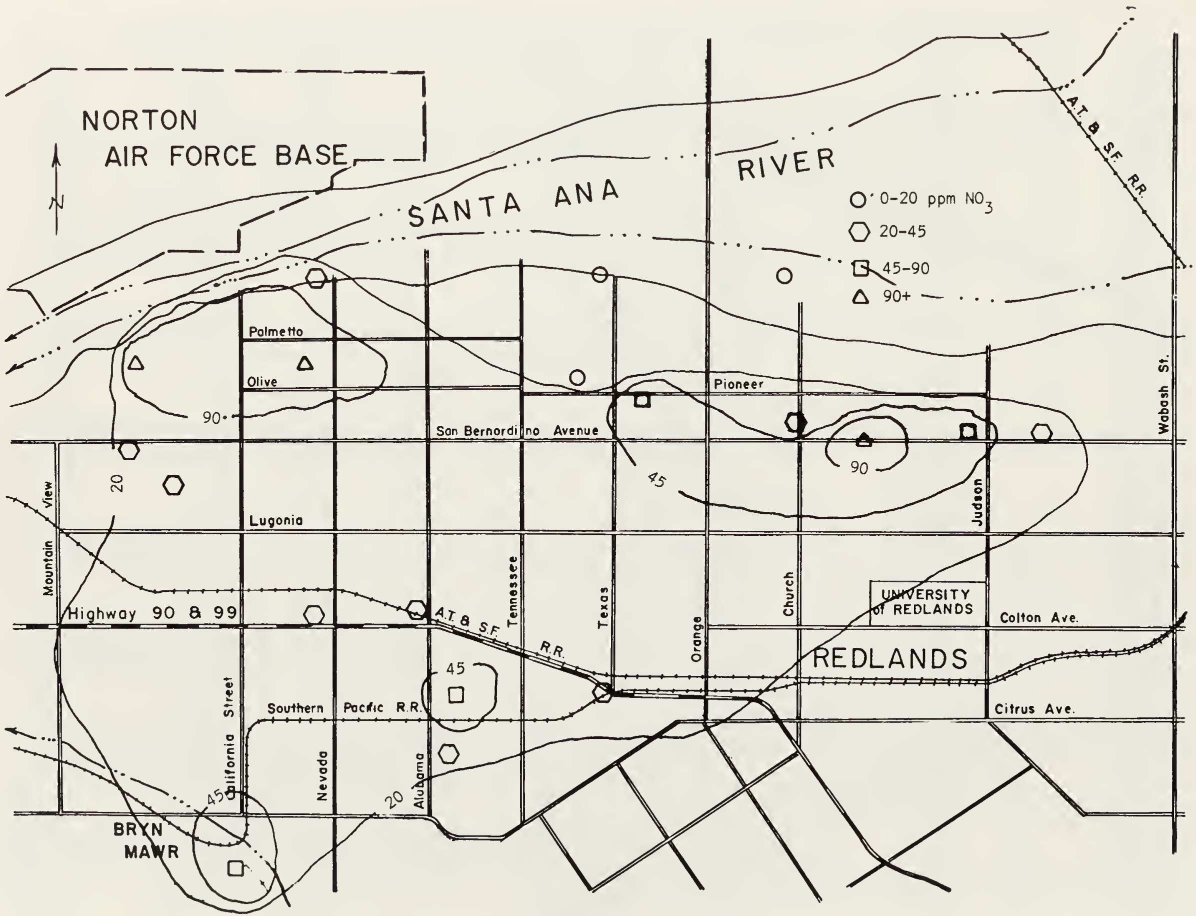


Fig. 6. Map of the Bunker Hill Sub-Basin showing nitrate concentrations of well waters between 1965 and 1968.

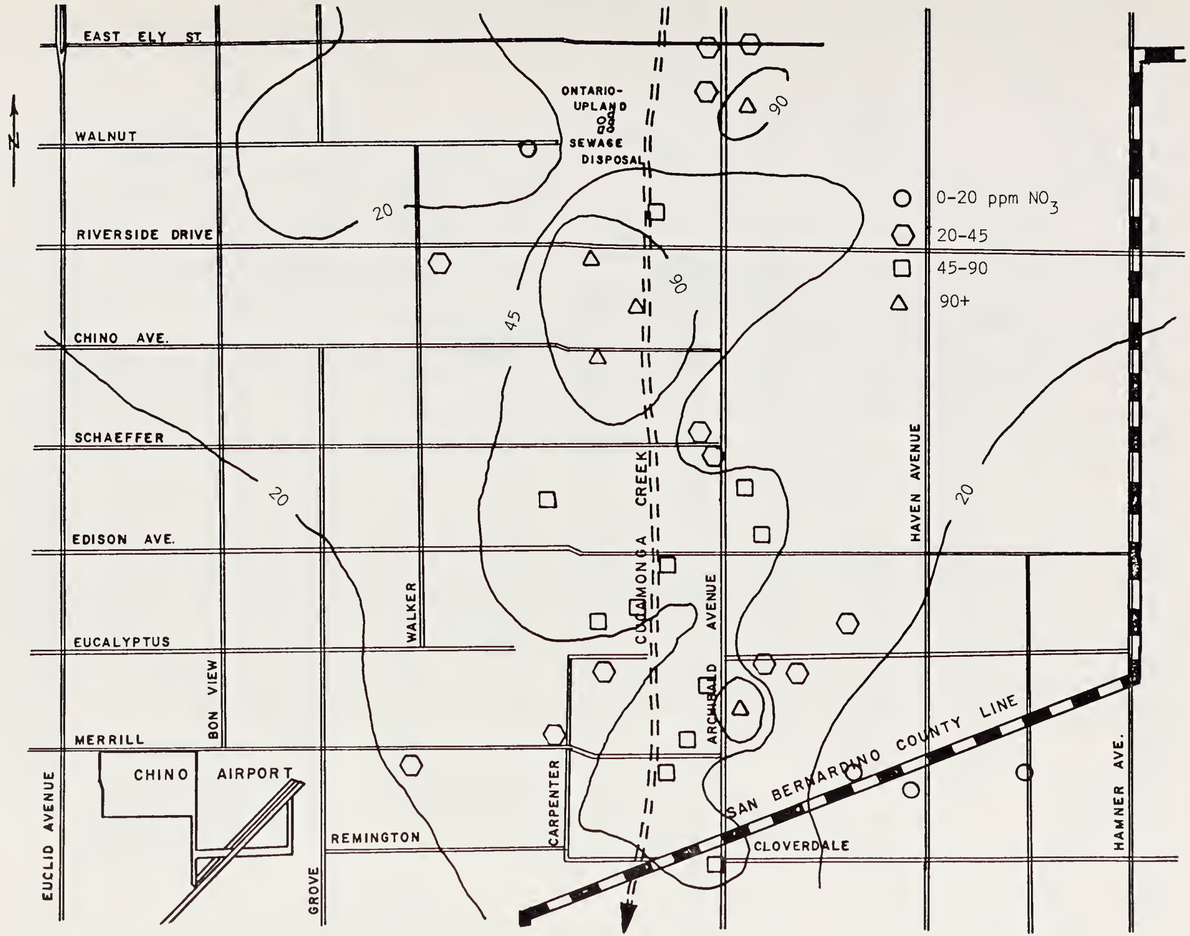


Fig. 7. Map of the Middle Chino Sub-Basin showing nitrate concentrations in well waters in 1950.

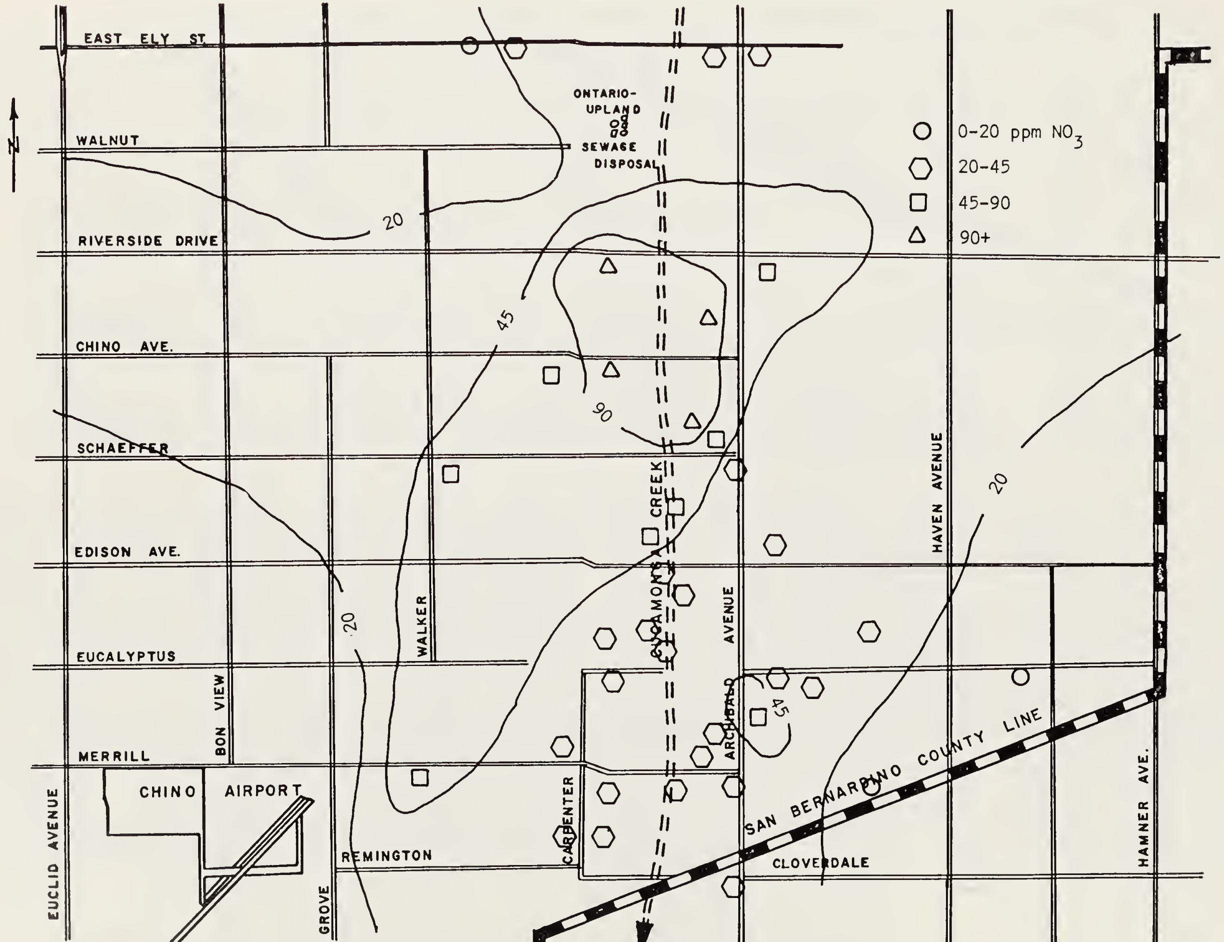


Fig. 8. Map of the Middle Chino Sub-Basin showing nitrate concentrations in well waters in 1960.

Fig. 9. Map of the Middle Chino Sub-Basin showing nitrate concentrations in well waters in 1968.

in 1950 or 1960. Only 19 wells were sampled during this period, thus further reducing the reliability of generalizations made about the area for this period. Even though nitrate levels are apparently lower (fig. 6), the pattern of high nitrate incidence near Redlands remains, and the areas of highest nitrate (above 90 ppm) described previously are still present. This Redlands area within the Bunker Hill Sub-Basin is discussed later in the report and is referred to as the Redlands area or the Bunker Hill Sub-Basin study area.

Middle Chino Sub-Basin

The area of well waters of highest nitrate reported from the Middle Chino Sub-Basin (also referred to as simply the Chino Sub-Basin) is centered on Cucamonga Creek and extends from about Riverside Drive on the north to the San Bernardino County Line on the south—an area about 3 miles long and 1.5 to 2 miles wide.

1930–1940 nitrate situation. Because there are no known analyses from this limited area prior to 1950, it is not possible to state with certainty the concentration of nitrate during 1930–40 and earlier.

1950 nitrate situation. Analyses of well waters indicate that nitrate concentrations were high in this area in 1950. The general pattern of nitrate is reflected in water analyses from 32 wells (fig. 7). Five wells yielded water containing more than 90 ppm NO_3^-; 11 were 45–90 ppm; 12 were 20–45 ppm; and 4 were less than 20 ppm NO_3^-. Three of the wells with highest nitrate (above 90 ppm) were close to one another in the north-central portion of the basin, with the two others at some distance. Wells with slightly lower nitrate (45–90 ppm NO_3^-) were mostly south (downslope) from the highest nitrate area.

1960 nitrate situation. The distribution of nitrate follows the same general pattern in 1960 as in 1950, with a slightly changed westerly trend for the southern part, away from the present Cucamonga Creek channel, on which the 1950 pattern centered (fig. 8).

1968 nitrate situation. The distribution pattern in 1968 (fig. 9) resembles that in 1950, which was centered on Cucamonga Creek. The wells of highest nitrate (greater than 90 ppm NO_3^-) remain mostly in the north-central portion in Section 10 (T2S, R7W), with slightly lower nitrates downslope to the south.

Riverside-Arlington Sub-Basin

The Riverside-Arlington-Corona Sub-Basin is the most extensive area exhibiting high nitrate in its groundwaters (45 to 90 ppm). No detailed study has been attempted because the relatively few wells sampled are widely spaced and consistently produce nitrate waters.

Upper Chino Sub-Basin—Pomona Area

A small area manifesting high nitrate concentrations exists in the Upper Chino Sub-Basin in east Pomona, centered near Mission Boulevard and Reservoir Street. There are 14 wells within an area of about 200 acres, about half of which have consistently produced waters containing nitrate of 45 to 115 ppm. This high-nitrate area may be larger, but no water analyses are available for further delineation of the area.

Surface water quality of Santa Ana River

Average nitrate levels in the surface flows of the Santa Ana River have been rising steadily in recent years. This rise became most dramatic in about 1950 at the Riverside Narrows, and in 1954 below Prado Dam. The average nitrate level in the total annual surface flow of water was reported to be approximately 30 ppm at Riverside Narrows in 1965 and 1966, and about 28 ppm below Prado Dam in 1966 and 1967. Figures 10 and 11 show these changes in nitrate in surface flows—in 15 years nitrates increased from about 10 to nearly 30 ppm.

Nitrate levels vary with flow of the river. Figures 12 and 13 show the variation of nitrate with river flow during October 1966 to October 1967 at two locations, Colton and below Prado Dam. At Colton, nitrates in the river varied from a high of 99 ppm on May 31, 1967 (fig. 12) with

Fig. 10. Nitrate concentrations in the Santa Ana River below Prado Dam as a function of time.

a flow of 150 cfs, to a low of 2.5 ppm on January 6, 1967, with a flow of 25 cfs. Below Prado Dam (fig. 13) nitrate concentrations varied from a high of 40 ppm (on August 11, 1967) with a flow of 28 cfs, to a low of 10 ppm with a flow of 1130 cfs on December 8, 1966. Below Prado Dam nitrate concentrations increase as flows decrease, but at Colton this is not necessarily the case. At Colton, nitrates in the summer months increase with increased flow. Flow is intermittent along the course of the Santa Ana River, and surface flows may occur only at faults, barriers, or topographic constrictions, where groundwaters rise temporarily to become surface flows and then soon disappear again to rejoin underground waters. This is the case with surface waters at Colton and Riverside Narrows, and be-

Fig. 11. Nitrate concentration in the Santa Ana River at the Riverside Narrows as a function of time.

Table 5

SANTA ANA RIVER BASIN WATER-QUALITY DATA, NITRATE FLOW (SANTA ANA RIVER AT COLTON)*

Date	Discharge	Nitrate concentration	Nitrogen exported†
	cfs	*ppm*	*lb. per 30-day period*
10/10/66.....	38	54	75,555
11/4/66......	15	96	53,021
12/8/66......	400	36	530,208
1/6/67......	25	2.5	2,301
3/22/67.....	12	30	13,255
4/6/67......	15	30	16,569
5/4/67......	15	25	13,808
5/31/67.....	150	99	546,777
7/11/67.....	100	62	228,284
8/11/67.....	50	55	101,255
8/31/67.....	35	32	41,238

* U.S.G.S. Water Resources Data for California, Part 2, Water Quality Records, 1967, p. 52–53.
† Flow and nitrate reported on given date assumed as representing flow during period prior to next sampling date.

Table 6

SANTA ANA RIVER BASIN WATER-QUALITY DATA, NITRATE AND FLOW (SANTA ANA RIVER BELOW PRADO)*

Date	Discharge	Nitrate concentration	Nitrogen exported†
	cfs	*ppm*	*lb. per 30-day period*
10/11/66.....	48	28	49,486
11/4/66......	30	20	22,092
12/8/66......	1130	10	416,066
1/6/67......	62	33	75,334
2/9/67......	62	28	63,920
3/22/67.....	60	30	66,276
4/6/67......	70	19	48,971
5/4/67......	52	23	44,037
5/31/67.....	45	24	39,766
7/11/67.....	30	29	32,033
8/11/67.....	28	40	41,238
8/31/67.....	21	32	24,743

* U.S.G.S. Water Resources Data for California, Part 2, Water Quality Records, 1967, p. 52–53.
† Flow and nitrate reported on given date assumed as representing flow during period prior to next sampling date.

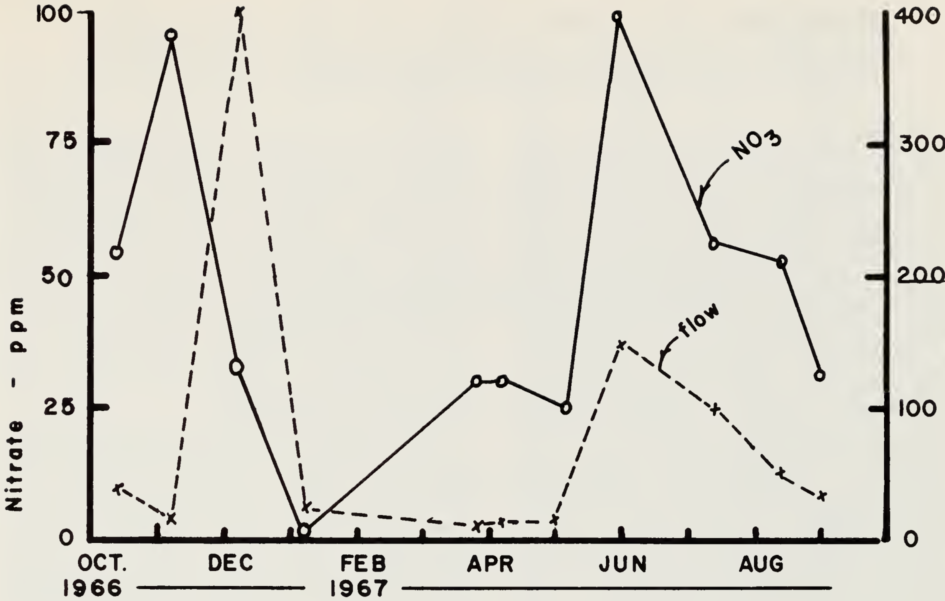


Fig. 12. Nitrate concentration and rate of water flow in the Santa Ana River at Colton as a function of time.

low Prado Dam—the nitrate levels of these surface waters may therefore reflect changing nitrate levels in these basins.

Tables 5 and 6 show that from October, 1966 to August 1967, about 1.8 million pounds of nitrogen were measured at Colton (exported from Bunker Hill Sub-Basin) and about 0.9 million pounds at Prado Dam. During this period half the nitrate equivalent measured at Colton was exported over Prado Dam. Thus, available data indicate that concentrations of nitrate are high in underground water supplies in: the Bunker Hill Sub-Basin (Redlands to Norton Air Force Base), the Middle Chino Sub-Basin (Laird area), the Riverside-Arlington Sub-Basin, and the Upper Chino Sub-Basin (East Pomona area). Levels of nitrate are moderately high in surface waters of the Santa Ana River at Colton and Riverside Narrows, and below Prado Dam.

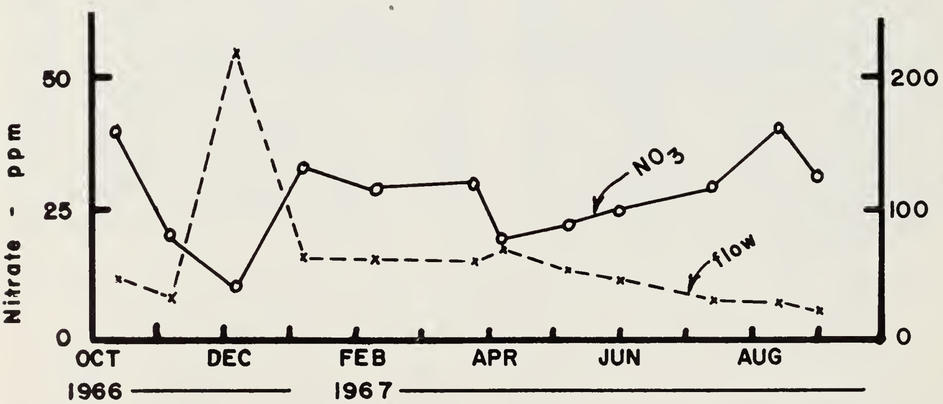


Fig. 13. Nitrate concentration and rate of water flow in the Santa Ana River below Prado Dam as a function of time.

HISTORY OF LAND AND WATER USE AND WASTE DISPOSAL IN EACH AREA STUDIED

To determine the cause of nitrate accumulation in some groundwaters major nitrogen inputs to the Upper Santa Ana Basin were studied, along with factors effecting movement of nitrate nitrogen downward and laterally. Inputs investigated included mainly agricultural fertilizers and wastes from dairy cows, poultry, and humans. Other recognized sources of nitrogen include: native or fossil nitrogen accumulated under natural conditions (before agricultural development); nitrogen fixed from the atmosphere by leguminous plants; nitrogen fixed by non-symbiotic microorganisms; and nitrogen fixed by electrical storms and internal combustion engines. These sources of nitrogen were studied and related to movement on the basis of examination and analysis of nitrogen transformations, soil permeability, irrigation water use, and surface and groundwater hydrology.

Early land-use patterns. Limited agriculture, mostly extensive grazing by livestock, was introduced to the general area of the upper Santa Ana Basin by the Franciscan missionaries in 1810. The Mormon colony of San Bernardino planted their first grain crops in 1852, and the first citrus in the area was planted about 1870. By 1900, much of the present older citrus areas had already been planted. Land-use maps (1939 to 1940) of the Soil Conservation Service show both the Bunker Hill Sub-Basin (fig. 14) and Middle Chino Sub-Basin area (fig. 15) completely developed for irrigation agriculture. The Bunker Hill Sub-Basin area was mostly in citrus, and the Middle Chino was in field crops, alfalfa, and vegetables. In 1940, much of the Riverside-Arlington area was still in citrus, and the Pomona area in deciduous fruit and citrus. Present land use (1971) is still citrus in Bunker Hill Sub-Basin, whereas in Middle Chino it is changing rapidly from intensive irrigated agriculture to dairies with animals confined to limited acreage, averaging 10 animals per acre. In Riverside-Arlington, urbanization is replacing citrus, rapidly in some areas but more slowly in others. In Pomona, urbanization is complete.

The change in land use from agricultural to urban has been accelerating markedly since 1950. Agriculture is being displaced, either out of the drainage basin or elsewhere within the basin, to lands formerly farmed less intensively (DWR, Upper Santa Ana River Drainage Area, Land and Water Use Survey, 1964).

Citrus acreage and nitrogen fertilization. For 30 years citriculture land use has remained at about 20,000 acres in Riverside County, but in San Bernardino County it has decreased steadily from 50,000 to about 20,000 acres.

Many early studies of nitrogen fertilizer use on citrus in California indicated that maximum returns required applications of 100 to 350 pounds of nitrogen per acre annually. Because long-term fertilizer experiments at the University of California Citrus Experiment Station indicated annual needs of about 300 pounds of nitrogen per acre for maximum returns, many growers adopted this as a minimal rate.

A 1937 manual published by a Redlands-based citrus marketing organization states: "Condensing the fertilizer problems to their simplest terms, one would recommend the practice of applying 8 to 10 tons of some roughage manure to the acre, each year, and then to add two to

CITRUS ACREAGE IN RIVERSIDE AND SAN BERNARDINO COUNTY PORTIONS OF SANTA ANA BASIN

	1930	1940	1950	1960	1970
Riverside County	19,821	21,122	19,252	16,413	23,992
San Bernardino County	45,784	49,677	44,175	27,084	18,945

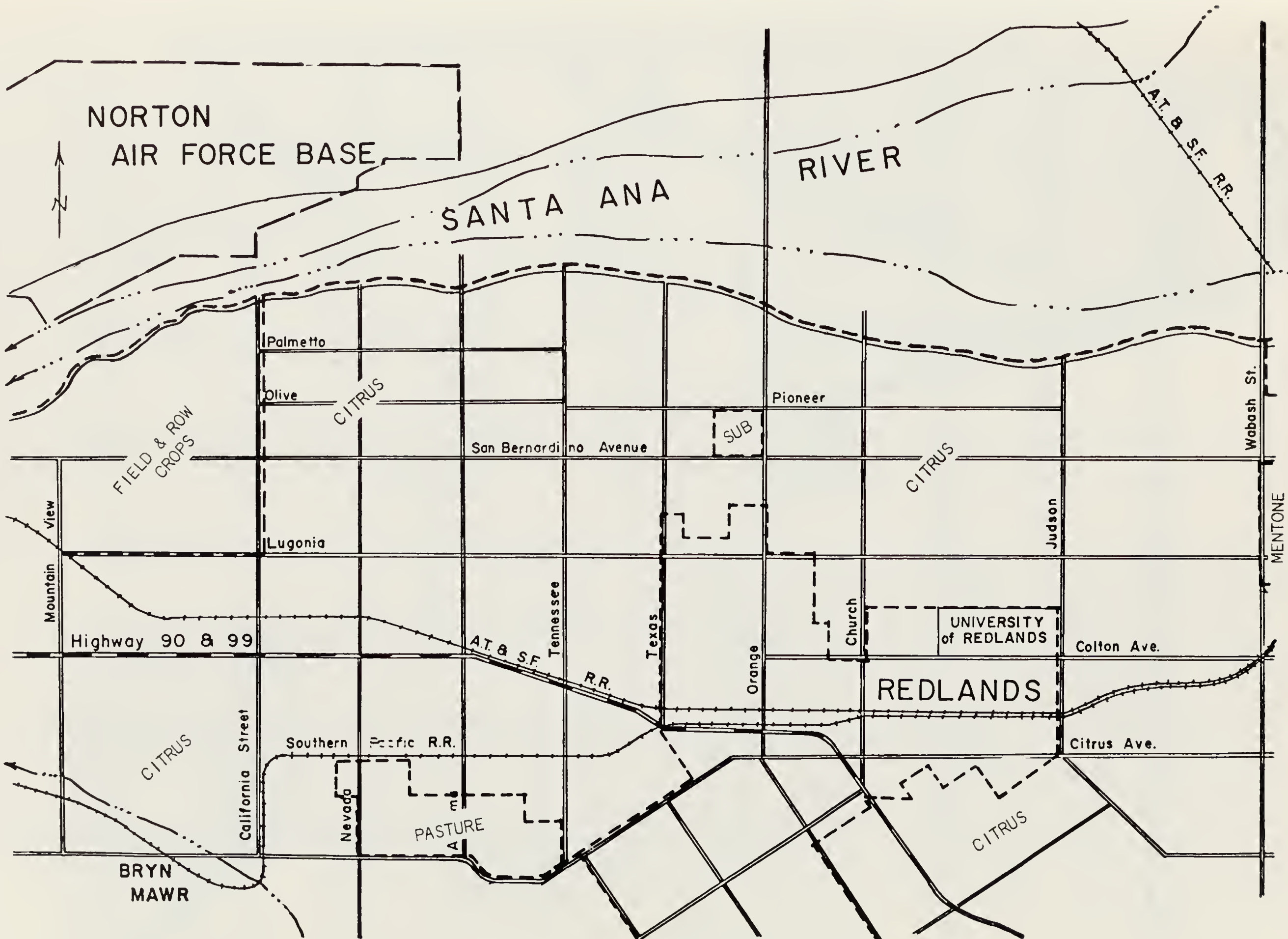


Fig. 14. Map of the Bunker Hill Sub-Basin showing land use between 1939 and 1940.

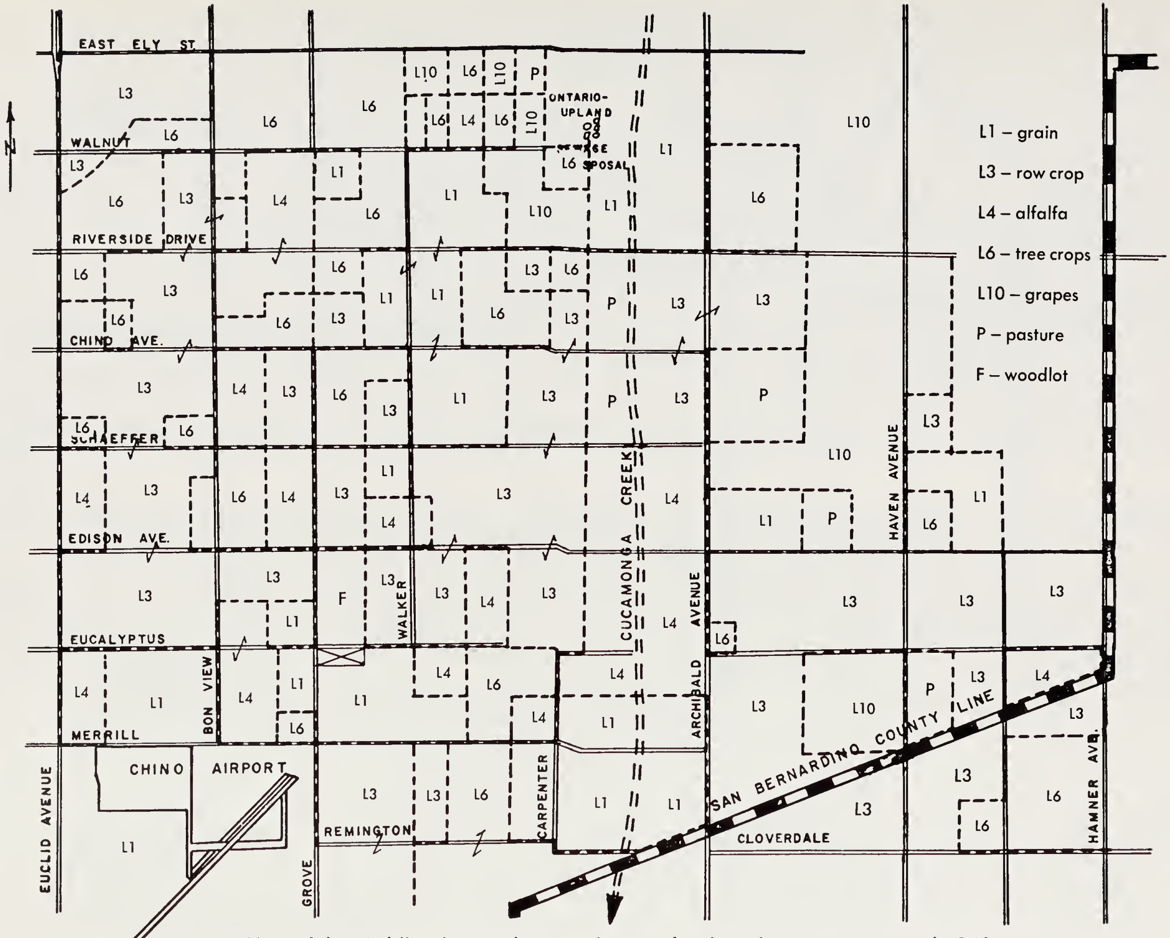


Fig. 15. Map of the Middle Chino Sub-Basin showing land use between 1939 and 1940.

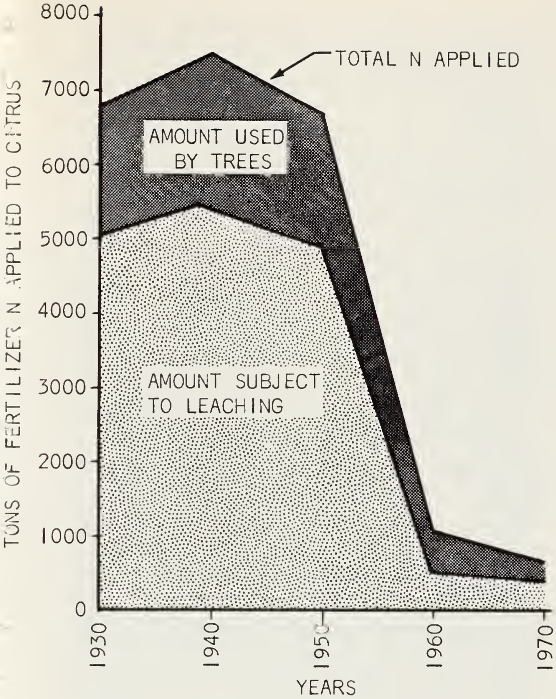


Fig. 16. Fertilizer nitrogen applied to citrus, amount used, and amount available for leaching in the Santa Bernardino County portions of the Upper Santa Ana Basin.

three pounds of quickly available actual nitrogen to the tree each year. This is the basic practice most followed in most California citrus groves. . . ." A survey reported in 1954 showed that 23 of the 26 growers interviewed in Riverside and San Bernardino counties were using an annual inorganic application of 2.5 to 5 pounds of nitrogen per tree (about 250 to 500 pounds per acre). More than half of these growers applied an additional 0.5 to 1 pound of nitrogen (50 to 100 pounds per acre) in the form of manure.

The San Bernardino County Farm Advisor estimates that about 300 pounds of nitrogen per acre was applied as fertilizer annually prior to 1960; he further estimates that current usage is from 0 to 100 pounds of nitrogen per acre. The Farm Advisor's estimates for usage prior to 1960 is about the same for Riverside County as the estimate for San Bernardino County. Since 1960, according to the Riverside County estimate, about 150 pounds of nitrogen per acre is applied annually. Figures 16 and 17 show the tons of fertilizer applied to citrus, nitrogen used, and nitrogen available for leaching, in the Riverside and San Bernardino County portions of the Upper Santa Ana Basin since 1930; the graphs were prepared with the following basic assumptions:

15,000 pounds of fruit (300 boxes) produced per acre annually

300 pounds of nitrogen applied per acre annually prior to 1960, and 75 pounds of nitrogen applied per acre annually in San Bernardino County and 150 pounds in Riverside County in subsequent years

2.5 pounds of nitrogen removed per ton of fresh fruit; and 20 per cent of applied nitrogen lost by volatilization or denitrification.

A decrease in total fertilizer nitrogen applied to citrus, which became particu-

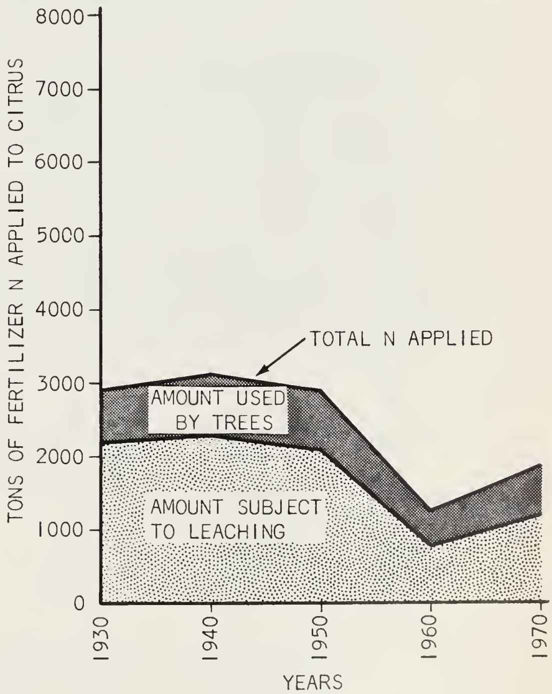


Fig. 17. Fertilizer nitrogen applied to citrus, amount used, and amount available for leaching in the Riverside County portions of the Upper Santa Ana Basin.

larly evident after 1950, was associated with a reduction in citrus acreage and the development of leaf analysis as a guide to fertilization. Experiments conducted in many privately owned orchards at about that time showed that 100 to 150 pounds of nitrogen per acre from chemical sources gave yields equal to those from higher rates. Leaf analysis studies continued, and now an estimated 85 to 90 per cent of the citrus acreage in the Upper Santa Ana Watershed is fertilized on the basis of leaf analysis programs.

Leaf analyses used initially indicated that many orange growers were applying more nitrogen than was needed by their trees. On one grove in Orange County, production was maintained for 10 years without nitrogen being included in the fertilizer program. The soil, mapped as a Yolo loam, had a past history of repeated manure applications and also received about 50 pounds of nitrogen per acre annually in the irrigation water. This 50 pounds per acre will not support the trees indefinitely, but leaf analyses will indicate fertilization need whenever critical levels are approached.

Another such example (not published) was found in an orange orchard near Bryn Mawr, a few miles south of the Bunker Hill study area (tables 7 and 8). In none of 8 years treatment—nor in the mean of the 8 years—was there an indication that nitrogen rates significantly influenced yields, even though significant differences were induced in leaf nitrogen. The optimum range in leaf nitrogen for oranges has been reported as 2.4 to 2.6 per cent nitrogen (table 9). The trees receiving no fertilizer nitrogen were above 2.4 per cent nitrogen in all but one year. Occasional analysis of the irrigation water indicated that it was supplying slightly more than 50 pounds of nitrogen per acre annually.

In these two examples, withholding nitrogen from the fertilizer programs for 8 to 10 years did not reduce yields significantly. Crop use of the nitrate in the irrigation water undoubtedly reduced the nitrate content of waters percolating downward beyond the rooting zone.

Leaf standards are better developed for oranges than for grapefruit and lemon. Economic nitrogen rates apparently are higher for lemons than for oranges, as the vigorous strains of lemon commonly planted today require more for maximum production. For mature lemon trees, about 300 pounds annually per acre appears to be economically feasible, although slightly higher yields can be obtained by applying more.

For oranges, technology is generally available to determine the nitrogen needs of the trees and to prevent over-use. Leaf analysis is being recommended for use in planning a fertilizer program.

Acreage and nitrogen fertilization of noncitrus fruit, nut, and field crops and of turfgrass. Acreage of noncitrus fruit and nut crops in the Upper Santa Ana Basin declined steadily from 1950 to 1970 and is now 17,489 acres, about one-third its earlier level. Grapes account for almost 90 per cent of the present acreage;

TABLE 7

YIELD OF VALENCIA ORANGES IN RELATION TO ANNUAL NITROGEN FERTILIZER PRACTICES

Annual rate of N applied	Dates of application	Yield (boxes per tree per year)*								
		1961	1962	1963	1964	1965	1966	1967	1968	Mean
lb. per acre										
—	—	1.62	3.01	7.26	3.86	4.94	2.94	9.00	0.60	4.11
100	February	1.41	3.32	7.51	3.94	4.66	2.84	9.92	0.68	4.23
100	February, July	1.76	3.20	7.60	4.05	5.04	3.35	10.34	0.75	4.45
300	February	1.65	3.37	7.65	4.07	5.00	3.25	10.20	0.73	4.43
300	February, July	1.39	3.36	7.18	3.77	5.23	2.60	9.21	0.58	4.09
100†	—	1.92	3.61	7.55	4.15	5.66	2.96	10.02	1.01	4.53

* Yields not significant statistically, all years.
† Three sprays; winter, spring and summer.

Table 8

NITROGEN CONTENT IN VALENCIA ORANGE LEAVES IN RELATION TO ANNUAL NITROGEN FERTILIZER PRACTICES, 1960–1969

Annual rate of N applied	Dates of application	Percentages of N in dry leaves from nonfruiting terminals sampled in the August-September period									
		1960	1961	1962	1963	1964	1965	1966	1967	1968	1969
lb. per acre											
	—	2.42	2.61	2.51	2.43	2.55	2.85	2.50	2.29	2.50	2.51
100.........	February	2.44	2.63	2.57	2.52	2.64	2.87	2.55	2.39	2.58	2.59
100.........	February, July	2.47	2.63	2.56	2.53	2.59	2.83	2.59	2.40	2.58	2.54
300.........	February	2.45	2.73	2.64	2.59	2.69	2.89	2.63	2.44	2.61	2.67
300.........	February, July	2.51	2.72	2.59	2.57	2.71	2.92	2.67	2.43	2.68	2.61
100*........	—	2.52	2.67	2.62	2.60	2.68	2.93	2.65	2.43	2.72	2.58
†Significance		**	***	***	***	***	NS	***	***	***	***

* Three sprays; winter, spring and summer.

† NS means not significant statistically; ** means significant at the 5% probability level; *** means significant at the 1% probability level.

the remaining acreage includes 14 other crops, none of which accounts for more than a few hundred acres. Nitrogen usage on noncitrus fruit and nut crops declined from a total of 1,777 tons in 1950 to 583 tons in 1970 (fig. 18). Rates of nitrogen fertilization range from 60 pounds per acre per year for grapes, to 300 pounds per acre per year for strawberries. (Grapes receive the lowest annual nitrogen application, but there is so much more grape acreage that it accounts for 80 per cent of the total nitrogen applied to noncitrus fruit and nut crops.)

Table 9

LEAF ANALYSIS GUIDE FOR DIAGNOSING NUTRIENT STATUS OF MATURE VALENCIA AND NAVEL ORANGE TREES*

Element	Unit (dry matter basis)	Ranges‖				
		Deficient	Low	Optimum	High	Excess
N............	per cent	<2.2	2.2 to 2.3	2.4 to 2.6	2.7 to 2.8	>2.8
P............	per cent	<0.09	0.09 to 0.11	0.12 to 0.16	0.17 to 0.29	>0.30
K†...........	per cent	<0.40	0.40 to 0.69	0.70 to 1.09	1.10 to 2.00	>2.30
Ca...........	per cent	<1.6	1.6 to 2.9	3.0 to 5.5	5.6 to 6.9	>7.0
Mg...........	per cent	<0.16	0.16 to 0.25	0.26 to 0.6	0.7 to 1.1	>1.2
S............	per cent	<0.14	0.14 to 0.19	0.2 to 0.3	0.4 to 0.5	>0.6
B............	ppm	<21	21 to 30	31 to 100	101 to 260	>260
Fe‡..........	ppm	<36	36 to 59	60 to 120	130 to 200	>250
Mn‡..........	ppm	<16	16 to 24	25 to 200	300 to 500	>1000
Zn‡..........	ppm	<16	16 to 24	25 to 100	110 to 200	>300
Cu...........	ppm	<3.6	3.6 to 4.9	5 to 16	17 to 22	>22
Mo§..........	ppm	<0.06	0.06 to 0.09	1.10 to 3.0	4.0 to 100	>100
Cl...........	per cent	—	—	<0.3	0.4 to 0.6	>0.7
Na...........	per cent	—	—	<0.16	0.17 to 0.24	>0.25
Li...........	ppm	¶	—	<3	3 to 35	>35
As...........	ppm	¶	—	<1	1 to 5	>5
F§...........	ppm	¶	—	<1 to 20	25 to 100	>100

* With the exception of nitrogen values this guide can be applied for grapefruit, lemon and probably other commercial citrus varieties.

† Potassium ranges are for effects on numbers of fruit per tree.

‡ Leaves sprayed with Fe or Mn or Zn materials may analyze high in these respective elements, but the following growth may have values in the deficient range.[6]

§ From fruiting terminals, (Chapman, H. D. 1960).

‖ Based on concentration of elements in five- to seven-month-old, spring-cycle leaves from nonfruiting terminals. Leaves selected for analysis should be free of obvious tipburn, insect or disease injury, mechanical damage, etc., and from trees that are not visibly affected by disease or other injury.

¶ These elements are not known to be essential for growth of citrus.

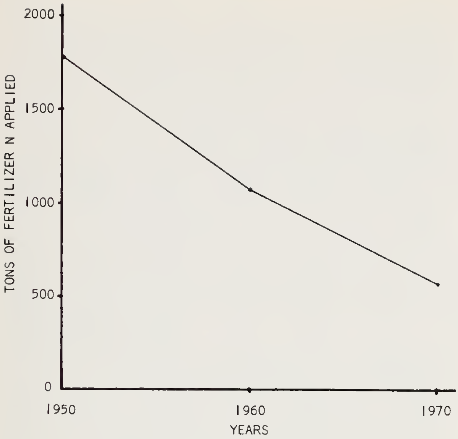


Fig. 18. Nitrogen fertilizer use on non-citrus fruit and nut crops in the Upper Santa Ana Basin as a function of time.

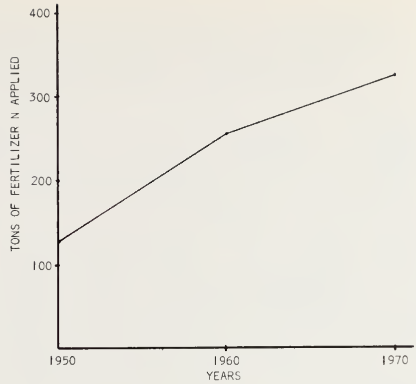


Fig. 20. Nitrogen fertilizer use on turf grass in the Upper Santa Ana Basin as a function of time.

Acreage of field crops in the Upper Santa Ana Basin declined from 48,639 acres in 1950 to 36,300 in 1970. Production is widely distributed, with the highest concentration (in the Chino district) having about 40 per cent of the total. Commercial nitrogen fertilization rates range from 0 pounds per year for dry beans, to 100 pounds for several other crops. Silage crops receive, in addition, high rates of manure applied as a disposal practice. Total commercial nitrogen applied to field crops in this Upper Basin

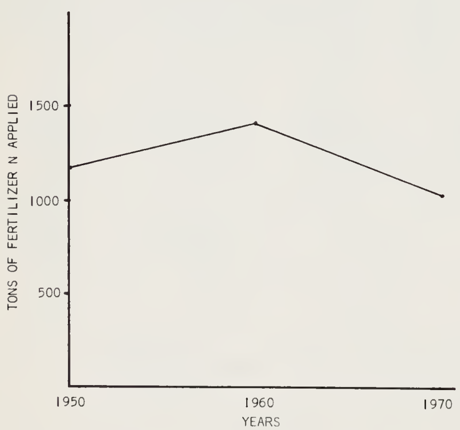


Fig. 19. Nitrogen fertilizer use on field crops in the Upper Santa Ana Basin as a function of time.

was 1,168 tons in 1950 and 1,038 tons in 1970 (fig. 19).

No turfgrass acreage figures were available. However, a detailed survey of all types of turfgrass in Los Angeles County in 1954 provided data for estimating acreage in the Upper Basin. When the Los Angeles County survey ratio of 76.3 persons per acre of turf is used, acreage in the Upper Basin is estimated to be 2,082 in 1930 and has increased progressively since, to 10,605 acres in 1970.

Rates of nitrogen fertilization of turfgrass vary considerably depending upon whether professional management is involved or not. Types of turf managed professionally (including golf courses, athletic fields, parks, commercial, etc.) receive an average of about 4 pounds nitrogen per 1,000 square feet per year—about 175 pounds nitrogen per acre per year. Homeowner-managed turfgrass, in contrast, receives an average of approximately 1 pound nitrogen per 1,000 square feet per year—about 40 pounds nitrogen per acre per year. Using data from the Los Angeles survey, the percentages of turfgrass under professional and homeowner management are estimated at respectively 14 per cent and 86 per cent. Estimated total nitrogen applied to all turfgrass types amounted to 130 tons in 1950 and increased to 322 tons in 1970 (fig. 20).

Vegetable crop acreage and nitrogen fertilization. In 1969, the Upper Santa Ana River Basin had about 5,000 acres of vegetables; in that year there were 2,000 acres of vegetables in San Bernardino County, mostly in the Chino Sub-Basin, and 3,000 acres in Riverside County, mostly in the Riverside-Arlington-Corona area. This is a considerable decrease from the 7,596 acres in vegetables in San Bernardino County alone in 1930, and doubtless it reflects the shift from irrigated agriculture to specialized dairy operations in the Chino Sub-Basin. Riverside County saw an increase from 1,971 acres in 1930 to 3,078 acres in 1969. Table 10 gives these data in more detail.

The rate of nitrogen fertilization of vegetables increased markedly between 1930 and 1969 (table 11). Average annual nitrogen rates are estimated to have been 30 to 45 pounds per acre in 1930, about 90 to 100 pounds in 1950, and about 180 pounds per acre by 1969. Crop yields have increased substantially as rates of fertilization have increased, so it has been extremely profitable to apply these additional quantities of fertilizer. While yields have gone up, however, the percentage of applied nitrogen recovered in the crop has gone down. With the low rates of 30 to 45 pounds nitrogen applied in 1930, as much as 65 to 75 per cent of the nitrogen applied was accounted for in the crop produced. By 1950, about 50 per cent of the applied nitrogen was in the crop, and by 1969 only about 40 per cent was recovered. The 60 per cent unaccounted for was presumably tied up in the soil-nitrogen pool, lost to the atmosphere as gaseous nitrogen from denitrification, or leached below the point where crops could recover it.

Concentration of nitrates in drainage water reaching the water table can be reduced by: (1) reducing total rates of nitrogen applied to these vegetables crops—though at a resultant cost in lower crop yields (assuming optimum yield for rate of nitrogen formerly applied); (2) increasing water applied above consumptive use of the crop (more inefficient use of water); or (3) utilizing the best agricultural technology available for producing the best crop possible while recognizing that certain compromises may be necessary to reduce leaching losses at times when nitrates are most readily available for leaching.

Although plant analysis is useful in assessing the nitrogen status of vegetable crops, there are limits to its usefulness. Interpretation of leaf analysis values is based upon data developed from sampling of a specific part of the plant at a definite time or stage of development. By the time the proper stage of development has been reached for satisfactory evaluation of the nitrogen status, it is usually too late to apply additional fertilizer. The

TABLE 10

ACREAGE, ESTIMATED NITROGEN APPLICATION, AND ESTIMATED NITROGEN REMOVAL OF VEGETABLES IN RIVERSIDE AND SAN BERNARDINO COUNTIES, 1930–1969

Year	Number of acres		Total N applied		Pounds N per acre		Total N removed in crops		N excess (application less crop removal)	
	Riverside County	San Bernardino County	Riverside County	San Bernardino County	Riverside County	San Bernardino County	Riverside County	San Bernardino County	Riverside County	San Bernardino County
			thousands of pounds				*thousands of pounds*			
1930.....	1971	7596	59	342	30	45	48	228	11	114
1940.....	1109	5604	72	462	65	82	30	216	42	246
1950.....	1603	6797	144	709	90	105	66	379	78	330
1960.....	2248	6587	315	977	140	148	124	441	191	536
1996.....	3078	2647	539	482	180	182	209	198	330	284

Table 11

ESTIMATED NITROGEN APPLICATION AND REMOVAL BY VEGETABLE CROPS, UPPER SANTA ANA BASIN*

Year	Riverside County	San Bernardino County	Total	Pounds of N per acre available for leaching†
	thousands of pounds			
1930	11	114	125	12.5
1940	42	246	288	42.5
1950	78	330	408	48.5
1960	191	536	727	81.5
1969	330	284	614	107.1

* Nitrogen applied less crop removal. Assumes that all N removed in the crop came from fertilizer N applied.
† Calculated from total acres of vegetables for San Bernardino County and Riverside County and total pounds of N applied less removal by crop.

information obtained is of value, however, in determining fertilizer applications on subsequent crops grown under similar conditions. The text-tables immediately following provide guidelines for nitrogen fertilization and plant analysis of selected vegetable crops. Soil analysis prior to planting is most useful for helping growers decide on probable need for fertilization with phosphorus, potassium, and zinc. To a much less extent it may be useful in helping to decide whether nitrogen will be needed at planting, or if enough is present that the usual planting application may be reduced or eliminated.

Typical Rates of Nitrogen Fertilization (Vegetables)

Crop	Pounds of N per acre
Carrots	120
Celery	250–300
Melons	120
Potatoes	220
Strawberries	200
Tomatoes (canning)	100
Tomatoes (fresh-market)	200
Miscellaneous vegetables	120–150

These rates can be expected to produce near-optimum yields with a minimum excess of applied nitrogen. The recommendations are based on data from field experiments.

Waste disposal: trends in population and waste production by humans, cattle, and poultry. Disposal of nitrogenous organic wastes is a major problem in the Upper Santa Ana Basin. These nitrogenous organic wastes include sewage from people, manures from dairy and beef cattle and poultry, industrial wastes, crop residues, and other unclassified solid wastes.

Prior to World War II the Basin was mostly rural, with many small farms and a few isolated cities. Dramatic changes began in 1950, with a great influx of people to these cities, and with movement of dairies to the Chino Basin. This trend in movement of both people and the livestock industry continues today at an accelerated rate (figs. 21, 22, 23, 24). As a result, waste-load and nitrogen input into the Upper Santa Ana River Basin have increased tremendously (figs. 25, 26, 27). People and animals together contribute roughly 40 million pounds of nitrogen to the Upper Basin. Based on an estimate of 12 pounds nitrogen per capita per year, one dairy cow is equal to 12 people in nitrogenous waste-load produced, and 1,000 laying hens are equal to 90 people. About 77 per cent of the population of the Upper Basin is now (1971) served by municipal or district sewers, and these systems handle about 210 acre-feet of waste water per day in at least 10 different treatment plants.

In an activated-sludge secondary-sewage-treatment plant, solids are separated from water. The effluent is then usually allowed to percolate into the soil for disposal, and solids are dried and disposed of on or in the topsoil. During treatment,

PLANT ANALYSIS GUIDE FOR VEGETABLE CROPS

Crop	Time of sampling	Plant part	Deficiency levels NO_3^-–N (ppm, dry-weight basis)
Cabbage	At heading	Leaf midrib of wrapper leaf	5,000
Carrots	Midgrowth	Petiole of young mature leaf	5,000
Cauliflower	At buttoning	Midrib of young mature leaf	5,000
Celery	At midgrowth when 12–15 in. tall	Petiole of youngest fully elongated leaf	5,000
Lettuce	At heading	Leaf midrib of wrapper leaf	4,000
Melons	Early fruit set	Petiole of 6th leaf from growing tip	5,000
Pepper	Early fruit set	Petiole of young mature leaf	4,000
Potatoes	Tuber set	Petiole of 4th leaf from growing tip	6,000
Snap beans	Full bloom	Petiole of 4th leaf from growing tip	4,000
Spinach	Midgrowth	Petiole of young mature leaf	4,000
Sweet corn	At tasseling	Leaf midrib of 1st leaf above primary ear	500
Sweet potato	At midgrowth	Petiole of 6th leaf from growing tip	1,500
Tomatoes	Early bloom	Petiole of 4th leaf from growing tip	2,000

about 50 per cent of the nitrogen stays with the primary effluent. From 10 to 30 per cent of the nitrogen component in the primary effluent may be denitrified and lost as inert N_2 gas to the atmosphere in the secondary treatment process. The remaining nitrogen is in the sludge but tied up in organic form. Handling and disposal of this sludge is probably the most troublesome part of waste-water

POPULATION OF PEOPLE, CATTLE, AND POULTRY IN THE UPPER SANTA ANA BASIN EXPRESSED AS NUMBER OF PEOPLE ON THE BASIS OF NITROGEN WASTE PRODUCTION

Year	People	Cattle	Poultry	Total people equivalent for basin
1930	154,000	20,000 (est.)	—	394,000
1940	200,000	22,000 (est.)	—	464,100
1950	336,000	30,300	2,616,500	928,000
1960	658,000	71,200	6,399,300	2,148,500
1970	809,100	125,200	11,059,000	3,379,000

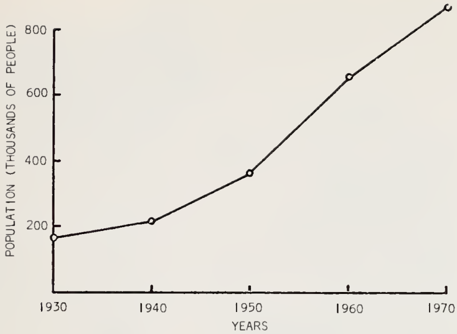


Fig. 21. Total population of people in the Upper Santa Ana Basin as a function of time.

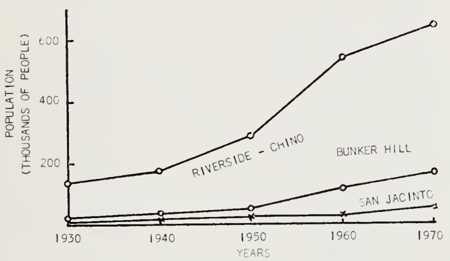


Fig. 22. Population of people in sub-basins of the Santa Ana Upper Basin as a function of time.

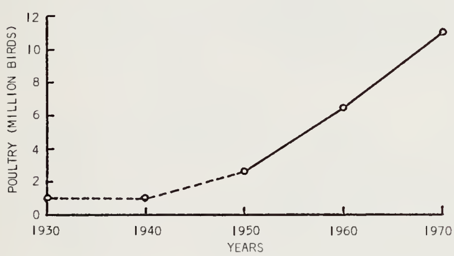


Fig. 23. Poultry population in the Upper Santa Ana Basin as a function of time. (Dotted line indicates estimate.)

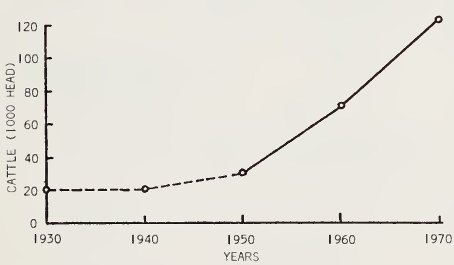


Fig. 24. Cattle population in the Upper Santa Ana Basin as a function of time. (Dotted line indicates estimate.)

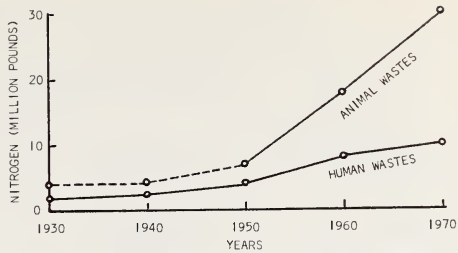


Fig. 25. Nitrogen contributed to the Upper Santa Ana Basin from wastes of animals and humans. (Dotted line indicates estimate.)

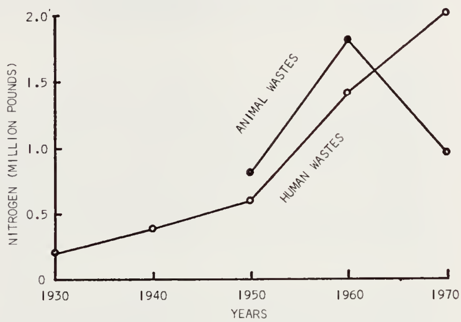


Fig. 26. Nitrogen contributed to the Bunker Hill Sub-Basins from wastes of animals and humans.

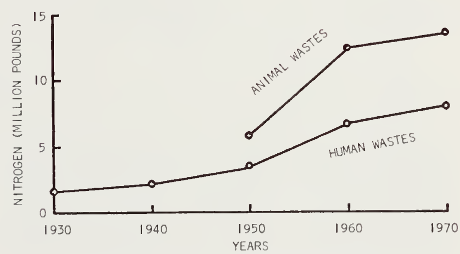


Fig. 27. Nitrogen contributed to the Chino-Riverside Sub-Basins from wastes of animals and humans.

treatment, particularly as it relates to groundwater pollution.

Most poultry manures and perhaps as much as 15 per cent of the beef and dairy manures are processed and/or exported from the Upper Basin. Disposal of remaining animal and human wastes is limited to a relatively small acreage of land, and loading rates no doubt greatly exceed the natural capacity to assimilate without resulting in pollution. Handling of animal wastes is less advanced than

handling of domestic waste—most animal wastes remain in the corral until semi-annual cleanout and disposal. Once manure is defecated, its composition changes rapidly. According to our estimates, approximately 50 per cent of the nitrogen in the wastes disappear before cleanup of the corral, through a combination of leaching, runoff, volatilization of ammonia, and denitrification.

In addition to manure solids, dairies also generate 50 to 100 gallons per cow of waste-water every day. In the Chino-Riverside area, this could amount to 9 million gallons per day (about 30 acre-feet per day). During the growing season, most of these waters are used on irrigated pastures.

Waste disposal in the Bunker Hill Sub-Basin study area. Redland's sewage-treatment plant has been located along the north edge of the Bunker Hill Sub-Basin Area since 1963. It has a primary settling basin and an activated-sludge secondary treatment, and produces 7.4 acre-feet of effluent a day containing 30 to 40 ppm of ammonia (equivalent to 103 to 138 ppm nitrate) and 40 ppm COD (Chemical Oxygen Demand) discharged into the Santa Ana River bed. The sludge is dried on a sand drying-bed, and supernatant liquid from the sludge digester is stored in a 0.5-acre lagoon; discharge from the lagoon is by evaporation and percolation only. Prior to completion of this plant, an older plant treated essentially the same amount of waste water, but no record is available for study of its operation though it is known that its effluent percolated into the river bed.

Waste disposal in Middle Chino Sub-Basin study area. The Ontario-Upland sewage-treatment plant is located at the north edge of the high-nitrate area of the Middle Chino Sub-Basin. The history of sewage disposal in this area dates back to 1915. In 1917, Upland joined Ontario and both cities utilized the golf course area as a sewage farm. In 1950, the system treated 11 acre-feet per day, with disposal mostly to the golf course. In 1959, disposal to the golf course was reduced to about 3 acre-feet per day. The present plant utilizes a pre-aerated primary settling tank; secondary treatment is split for parallel flow through two trickling filters. The effluent, containing 15 to 25 ppm ammonia (equivalent to 52 to 86 ppm of nitrate) is discharged onto an adjacent golf course or to a flood plain along Cucamonga Creek. The supernatant liquid from the digester is stored in ponds until it can be recycled through secondary treatment. Ponding of sludge and sand-bed drying could cause leaching of appreciable nitrogen through the soil profile. However, no full assessment has been made of contributions from these two treatment plants. It is suggested that a water analysis for the detergent ABS (alkylbenzosulfanate) might confirm the presence of sewage effluent in the ground-water supply. Its absence, however, does not preclude sewage contamination, since ABS is not as mobile as chlorides or nitrates and is degraded by soil microorganisms.

Although actual nitrate contributions from the specific sewage-disposal plants at these two primary study sites have not been evaluated, evaluation of a similar situation (San Luis Obispo County) was made by Perry R. Stout *et al.* (1965). This report states that Arroyo Grande sewage effluent contains nitrogen equal to 172 ppm of nitrate. The effluent flowed from the treatment plant into a series of percolation ponds, where it percolated through sandy soils to the underground. The percolation ponds were rotated and allowed to dry between fillings. Each pond was flooded about once a week. Soil-solution values for nitrate concentrations under these ponds were obtained from soil samples taken from 12 different sites. Nitrate concentrations in the soil solution in the surface foot of soil ranged from 15 to 2300 ppm. The greatest concentration of nitrates in the soil solution immediately above the zone of saturation at the 4-foot depth was 459 ppm. Appreciable quantities of nitrate at rather high concentration were reported to be contributing to contamination of the underground water supplies of this rather small basin.

Sewage disposal probably contributes to the nitrate problem in each of these two study areas. Further study could evaluate its contribution to the problem.

Poultry ranch near Santa Ana River bottom. (Courtesy Max Clover, UCR.)

Santa Ana River bottom near Rubidoux. (Courtesy Max Clover, UCR.)

Dairy ranch near Chino. (Courtesy Max Clover, UCR.)

Riverside city sewage treatment plant. (Courtesy Max Clover, UCR.)

RELATION OF NITRATE MOVEMENT TO GROUNDWATER HYDROLOGY

Potential for groundwater pollution by nitrogen additions. Nitrates are completely water-soluble and thus they can move in solution. Subsurface movement of dissolved nitrates is therefore controlled primarily by the movement of water, which in turn is related to the water content and geologic properties of the sediments making up groundwater basins. The Santa Ana groundwater basin has two major subsurface zones to be considered: the zone of aeration, and the zone of saturation. Each zone plays an important role in the transport of nitrates and in their storage.

The zone of aeration. This upper zone (from soil surface to water table) is characterized by pore spaces only partly filled with water. Water movement there is predominately as unsaturated flow, although local regions of saturated flow may sometimes be present in the soil profile. Movement of water and dissolved nitrates in this unsaturated zone is controlled by gravity plus pressure differences caused by variable soil-water content and chemical forces. The direction of water movement is predominately vertical, although local structural variations and changes in water content with depth cause some deflection from the vertical. Thus, a point application of water at the ground surface tends, in general, to diffuse or spread out over a narrow band down through the zone of aeration. This phenomenon becomes more pronounced as depth to water table increases. In general, nitrate movement through the zone of aeration will be slower than bulk-fluid movements because of dispersive and diffusive mechanisms.

The zone of saturation. In this zone, all voids are filled with water and the rate of water movement depends on the hydraulic and transmissive character of basin sediments, and on the hydraulic gradient. Direction of movement of water in this zone is a function of gradients, storage coefficients, and transmissive properties. Basin sediments vary in their properties, but the predominant direction of groundwater movement is parallel to that of the water table (i.e., horizontal). Only where there is an impermeable fault zone or significant up-thrust of bedrock is there any appreciable vertical velocity component of the flow. Variations produced by individual wells in the water surface profile have little over-all influence on general horizontal movement of water in the basin. Therefore, basin-wide vertical velocity components are relatively insignificant, with horizontal movements of water dominating. Because nitrates move with the water, factors which affect water flow will also have about the same effect on the nitrates. Additionally, dispersive mechanisms associated with the pronounced heterogeneity of substratum materials will influence the transport and mixing of nitrates.

Table 12 summarizes a few of the more important factors relating to flow. It is particularly noteworthy that horizontal movement in the nitrate study areas is exceedingly slow, ranging from 0.003 to 0.1 mile per year for the hydraulic gradients reported in each area. Therefore, the movement of a specific particle of water 1 mile downslope requires 10 years in the Riverside-Arlington area and 300 years in the Middle Chino Sub-Basin.

Figures 28 and 29 show idealized cross sections of the geology and changes in water level over the last 25 to 30 years for four hydrologic units of the basin. In most of the separate sub-basins of the Upper Santa Ana Basin, the groundwaters are usually unconfined and can be in hydraulic contact with the basin ground surface. Nitrate, therefore, can percolate readily (along with applied waters) through the zone of aeration to the water table. If localized layers of clays and silts are present, however, they will retard the downward movement of waters and serve as partially-confining aquifers. Such an area exists above the Bunker Hill Dike near San Bernardino; it extends eastward to about the Bunker Hill Sub-Basin study area and is an example of a confined aquifer having little hydraulic contact with the basin surface. Artesian pressures

Table 12

GEOMETRIC, PHYSICAL, AND HYDRAULIC VARIABLES IN FOUR SUB-BASINS OF THE UPPER SANTA ANA BASIN

Sub-basin	Geometric variables physical parameters*				Hydraulic variables*	
	Approximate area	Thickness of zone of saturation	Thickness of zone of aeration	Water permeability†	Hydraulic gradients	Horizontal water velocities near top of zone of saturation
	acres	*ft.*		*mi. per year*	*ft. per ft.*	*mi. per year*
Middle Chino..	2200	400–800 550	100–250 175	2–8 4	$4.7 \times 10^{-3} - 2.1 \times 10^{-3}$ 3×10^{-3}	0.003
Pomona........	Over 4000	300–600 400	200–400 300	0.1–3 1	$2.1 \times 10^{-2} - 8.6 \times 10^{-4}$ 2×10^{-3}	0.005
Redlands......	5900	400–900 500	150–250 200	2–7 5	$2.5 \times 10^{-2} - 3.8 \times 10^{-3}$ 4×10^{-3}	0.1
Arlington-Riverside....	Over 33,000	100–200 100	50–300 75	3–50 10	$9.5 \times 10^{-3} - 3.0 \times 10^{-3}$ 4×10^{-3}	0.1

* Parameters and variables based on order of magnitude estimates and information for 1965 obtained from State of California, Department of Water Resources, Southern District. Under-scored values represent tyical magnitudes.
California Department of Water Resources, Southern District. 1071. Computer printouts for hydrologic model runs. Personal communication.
† Water permeability values are averages in zone of saturation.

have existed in the past in this area.

Analysis of the data cited above, and of other hydrologic information, leads to several significant observations concerning movement of water and nitrates. In general, hydrologic responses are highly damped in space and time. Consequently, seasonal variations in withdrawal and recharge are reflected in changes in water levels taking place over months and years. The presence and movement of nitrates must also be associated with this slow movement of water, the damping mechanism of the zone of aeration, and the nature of the hydrologic responses in each Sub-Basin. Because of the slow horizontal movement of water, high nitrates persisting in groundwaters of some areas must be related directly to a nitrogen source in the soils or ground surface overlying these. Similarly, the slow vertical movement of nitrates through the zone of aeration suggests that high nitrates presently found in some wells can be accounted for only by events initiated many years ago. Specifically, changes in the groundwater quality may reflect changes in surface nitrogen levels that occurred over a span of tens or perhaps even hundreds of years.

A limited number of water quality analyses of water pumped from wells perforated at different depths within the zone of saturation indicate that higher nitrate concentrations occur in wells perforated near the top of the saturated zone, and that lower concentrations occur in wells perforated near the bottom of the zone of saturation. This is explained by the fact that vertical velocities are slight, so that vertical mixing of nitrate water resulting from accumulation of percolating nitrated waters in the upper saturated zone is slow. Where the zone of saturation is relatively thin (such as in the Riverside-Arlington area) mixing takes place more completely and nitrates appear to be mixed more uniformly with depth. Consequently, there is little evidence of nitrate variation with depth in that area.

Two other hydrologic factors need to be considered in explaining how nitrates are transported and mixed in the zone of saturation. One is the long-term change in water-table levels within the Upper Basin. The other is the annual fluctuation in water-table level due to summer pumping and winter recharge. Figure 30 shows the nature of these water-table fluctua-

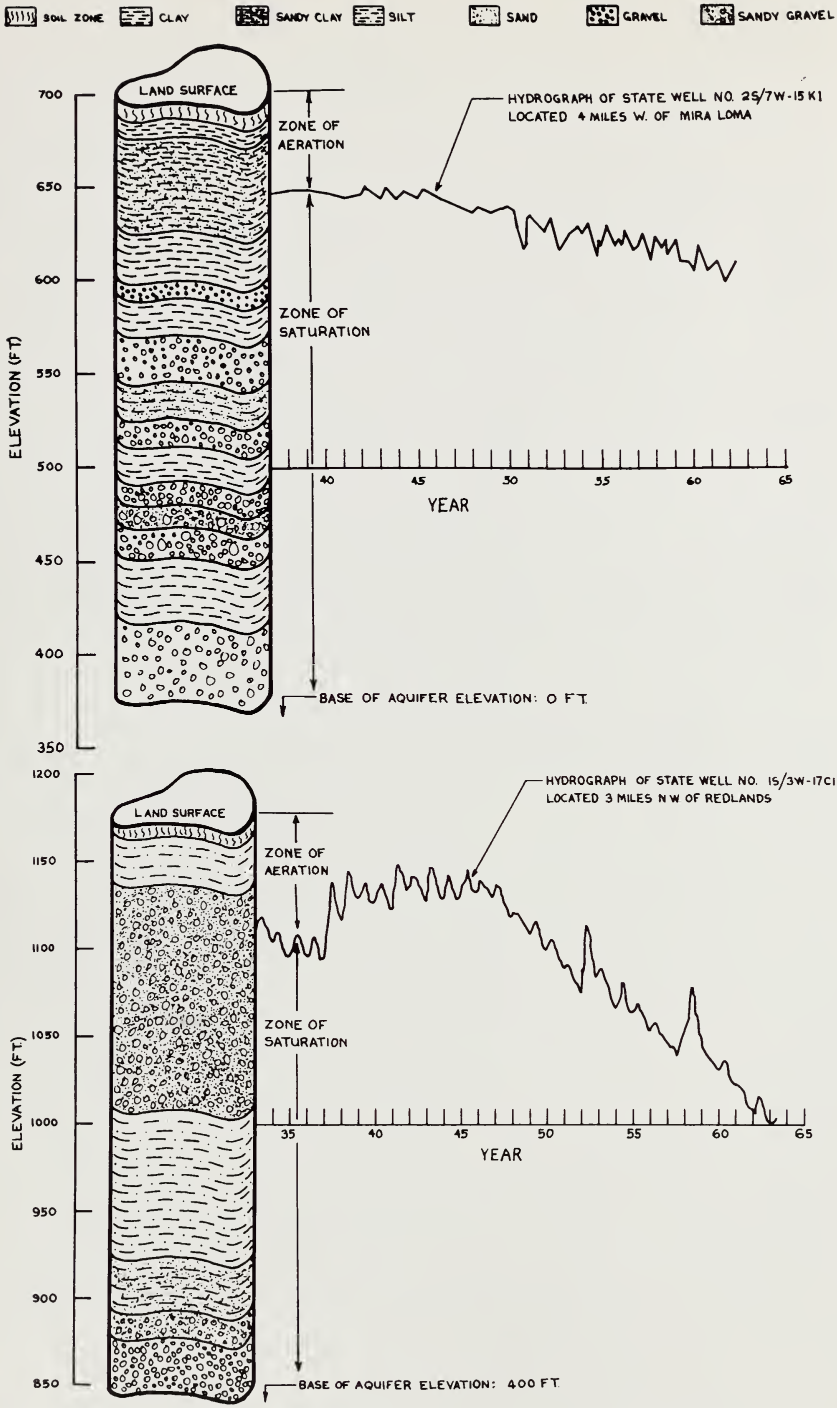


Fig. 28. Hydrographs and geology in the Middle Chino (upper) and Redlands (lower) areas.

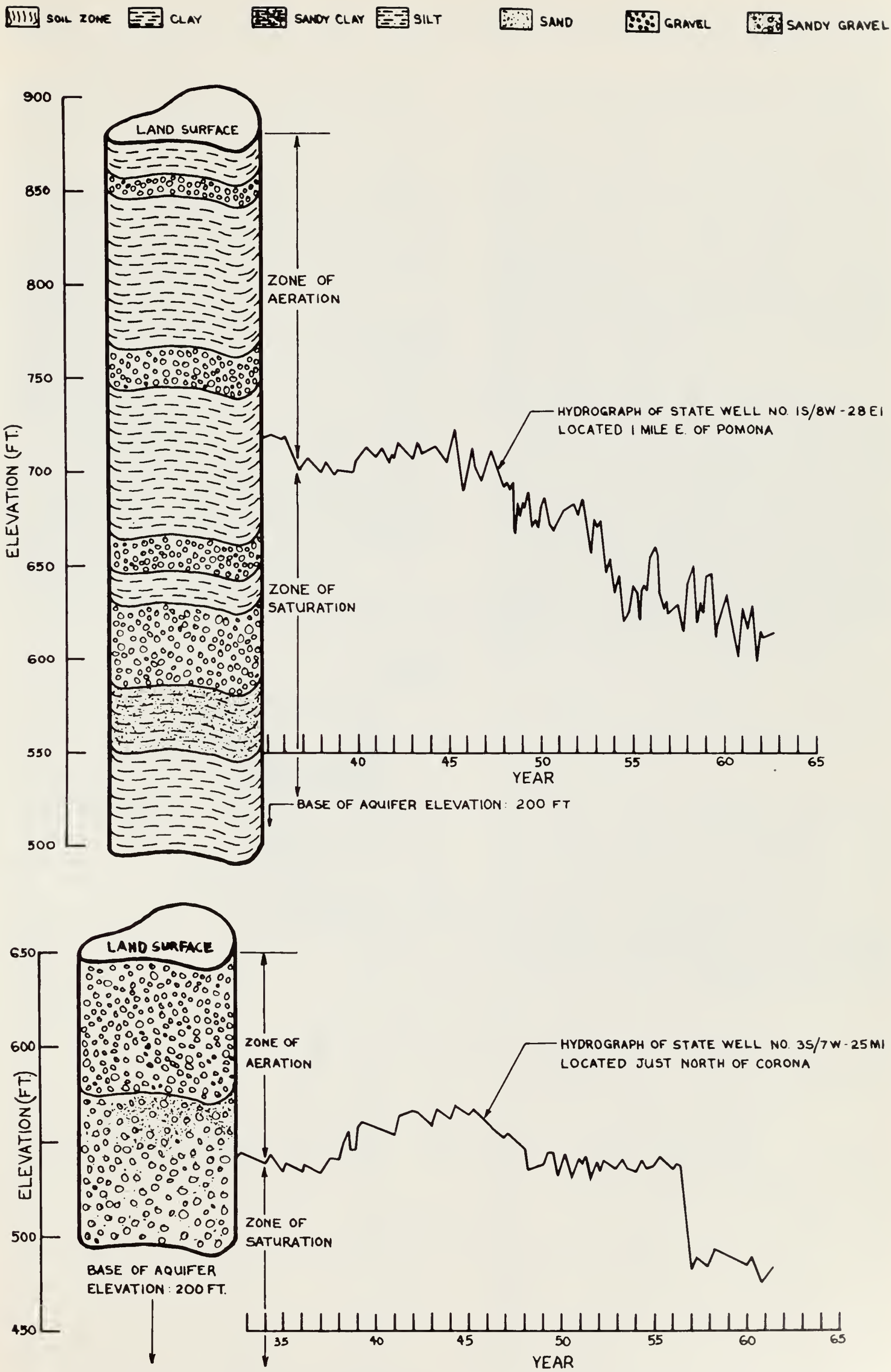


Fig. 29. Hydrographs and geology in the Pomona (upper) and Corona (lower) areas.

tions (coupled with nitrogen and water inputs) for an idealized geologic section and well hydrograph.

There are essentially three cases to be considered. The first assumes that a known concentration of nitrate (J_{NO3}) is moving through the zone of aeration to the water table. Then, the first situation is for periods when the water level is dropping faster than the percolating recharge waters are moving through the zone of aeration; here, no new accretions of nitrates from the surface take place. During such periods nitrate concentrations decrease at the water-table surface as nitrates which have previously moved from the surface are slowly mixed with the deeper groundwater; this results in an increase in nitrate with depth and time.

The second case is when the water table rises to intercept the downward-moving nitrates passing through the zone of aeration. In this case there would be a marked increase in nitrate concentration at the water table, assuming of course that nitrate concentrations moving through the zone of aeration are greater than those in the water table below.

The third case would be to assume that all nitrate additions to the zone of saturation would diminish with time because of imposed management practices. In this situation, previously contributed high nitrates from upper layers would continue to mix with waters of lower concentrations in the deeper layers; this would take tens or hundreds of years. The horizontal movement of nitrates would also take tens to hundreds of years, because the gradients are very low. This predicted mixing behavior assumes that the surface configuration of the water table within the Basin will remain essentially unchanged.

Some vertical mixing of nitrates takes place locally in the zone of saturation as a result of fluctuations of water tables produced by the pumping of individual wells. It is probable, however, that these effects are secondary to regional fluctuations in the water table.

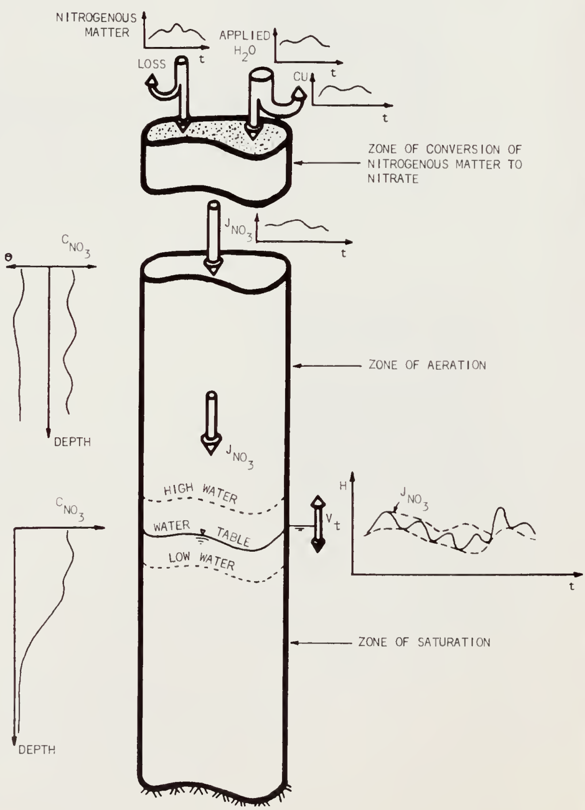


Fig. 30. Schematic diagram showing subsurface nitrate transport in relation to hydrologic responses.

SOIL CLASSIFICATION INFORMATION IN RELATION TO LEACHING AND DENITRIFICATION POTENTIAL

A study of the general patterns of soil associations in the Upper Santa Ana Basin led to the following three conclusions:

In general, nitrate concentrations are higher in groundwaters located below coarse-textured good agricultural soils (loamy sands, sandy loams) under intensive agricultural use.

Not all such areas of coarse-textured good agricultural soils under intensive agriculture are underlain by high nitrate concentrations in the associated groundwaters.

Soils of fine texture (clay loam and clay) or soils with subsoils which restrict downward movement of water may offer a useful potential for denitrification for reduction of the pollution of underground water supplies.

A general soil map of the central part of the Upper Santa Ana Basin was prepared by combining and correlating information from the general soil maps of southwestern San Bernardino, Los Angeles, and Riverside counties. (See pocket at end of this publication for the soil map and two other maps referred to below.) No information was available for the San Gabriel and San Bernardino Mountains, and the San Jacinto area was excluded. A second map depicts the relationship between soil associations and general land types and provides an over-all geographical picture of the area's soils. Each map depicts one or more extensive soils of similar characteristics, and may include minor areas of other soils. Soil associations are named for the major soil series contained. The patterns are useful for general investigation, whereas studies of specific sites require detailed maps and data on soil characteristics.

The second map mentioned above also shows the water-transmission potential of the Santa Ana Basin soil associations and their distribution pattern. Four classes, A through D, have been defined on the basis of their internal water-transmission characteristics. Each class is divided into two subclasses; the first subclass consists of soils having nearly level surfaces (slopes of less than 5 per cent), and the second consists of soils whose surfaces have slopes of more than 5 per cent. Classes C and D, which are soils having slower water-transmission potentials, are further differentiated by characteristics of this substrata; this differentiation recognizes unconsolidated sediments versus weathered or unweathered rock, consolidated sediments, or hardpans.

Water-transmission classes

High water-transmission potential. Soils in this class have high infiltration rates, and rapid permeability (in excess of 6.0 inches per hour) after being thoroughly wetted. They consist chiefly of well- to excessively-drained soils in sandy, sandy-skeletal, or fragmental families lacking strongly contrasting textural stratification below 40 inches. Such soils overlie substrata of transported materials that have not undergone consolidation. The nearly level subgroup has little to no runoff potential. The sloping subgroup has low runoff potential.

Moderate water-transmission potential. These soils have moderate infiltration rates and moderate to moderately rapid permeability (0.6 to 6.0 inches per hour) after being thoroughly wetted. They consist chiefly of well-drained and moderately well-drained soils in loamy skeletal or loamy families lacking clayey stratification below 40 inches. They overlie substrata of transported materials that have not undergone consolidation. The nearly level subgroup has a low-to-no-runoff potential. The sloping subgroup has a moderately low runoff potential.

Low water-transmission potential. These soils have slow infiltration rates and slow to moderately slow permeability (0.06 to 0.6 inches per hour) after being thoroughly wetted. They consist of well-drained or moderately well-drained soils in loamy skeletal, clayey skeletal, loamy, or fine families, with the exception of soils with a clay pan. They may have strongly contrasting textural stratification below 40

inches. Some soils may overlie weakly cemented or indurated but fractured hardpans. Beneath the soils there are substrata of transported materials that have not undergone consolidation, or there may be softly consolidated rock, deeply weathered rock, or deeply-fractured unweathered rock. Where a rock substratum is present the overlying soils may be moderately to rapidly permeable. The nearly level subgroup has a moderately low to no runoff potential. The sloping subgroup has a moderately high runoff potential.

Very low water-transmission potential. These soils have an extremely slow infiltration rate when thoroughly wetted, and are very slowly permeable or impermeable (less than 0.06 inches per hour). They consist of: clay soils with a high swelling potential; soils or land types with a permanently perched high water table; soils with clay pans; and other soils over unjointed nearly impervious material such as unweathered rock or indurated hardpan. Except for soils over unjointed unweathered rock, the substrata may range from pervious to impervious. The nearly level subgroups have moderately high to no runoff potential. The sloping subgroups have a high runoff potential.

Denitrification potential classes

The second map referred to on page 41 shows the denitrification potential of soils in the Basin. Three classes were defined by the following criteria:

LOW ...... Little or no denitrification can be expected under natural conditions, and difficult to induce the process artificially.

MODERATE . Seasonal or periodic zones of denitrification can be expected within the soil mass. Moderate effort is required to induce extensive denitrification within the soil.

HIGH ...... Denitrification processes occurr normally unless soil is drained artificially. Processes are extensive through the soil at a depth where all components necessary for denitrification coincide. Denitrification processes can be easily induced.

The denitrifying process in soils will take place if:

- denitrifying organisms are present (these are facultative microorganisms and are normally present)
- a suitable substrate for the denitrifiers is present (normal humus provides a substrate for nominal population; partly or undecomposed organic matter incorporated into the soil will greatly increase microbial activity and population).
- an anaerobic state exists in the soil, and nitrogen is present in the soil in an oxidized state (nitrate, nitrite).

Soil properties which influence development or lack of development of denitrification include:

- general drainage
- porosity and permeability of a soil, either in general or in localized zones within a soil body
- texture
- structure
- surface slope
- nature, amount, and location of organic matter within the soil.

WATER REQUIREMENTS FOR CROPS IN RELATION TO NITRATE LEACHING

Estimates of water use by crops in the Upper Santa Ana Basin have been obtained from University of California Farm Advisors, who have obtained data from surveys among growers, from trials conducted in cooperation with growers, and from measurements made by power companies, irrigation districts, or growers' ditch riders. Tables 13, 14, and 15 show that irrigation applications tend to be high, and that they have not appreciably diminished with adoption of sprinkler irrigation systems, probably because of the hazard of soil salinization. Contributing

Table 13

ANNUAL WATER APPLICATION, AND TOTAL USE, EASTERN SAN BERNARDINO COUNTY

Crop	Acreage	Estimated irrigation	Rain	Evapo-transpi-ration	Runoff and percolation	Total water application	Total water loss
		acre-inches per acre				acre-feet	
Citrus							
Sprinklers	2,671	54	13.7	32.1	35.6	15,067	7,925
Surface	12,859	60	13.7	32.1	41.6	78,067	44,694
Avocado	51	54	13.7	34.7	33.0	288	140
Walnuts	103	30	13.7	28.9	14.8	375	127
Deciduous	559	48	13.7	31.9	29.8	2,874	1,388
Grapes	3,555	16	13.7	21.6	8.1	8,799	2,400
Alfalfa	728	60	13.7	54.4	19.3	4,471	1,171
Cereals, grain	1,065	3	11.3	22.3	−8.0	1,268	
Cereals, hay	1,455	12	12.0	21.3	2.7	2,910	327
Corn							
Sudan silage	72	39	1.8	20.6	20.2	245	121
Pasture	610	54	13.7	51.2	16.5	3,144	839
Sugar beets	100	54	12.7	49.5	17.2	556	143
Dry beans	190	36	0.9	22.0	14.9	584	236
Strawberries	15	77	13.5	32.1	58.4	113	73
Lettuce, endive	120	33	11.5	12.5	32.0	445	320
Cabbage	69	33	11.5	18.0	26.5	256	152
Egg Plant							
Cantaloupe	55	30	1.8	19.1	12.7	146	58
Onions (dry)	40	60	6.8	33.1	33.7	223	116
Turf							
commercial	850	60	13.7	47.3	26.4	5,221	1,870
domestic	4,311	48	13.7	47.3	14.4	22,167	5,173
Totals	26,478					147,516	67,273

Table 14

ANNUAL WATER APPLICATION, AND TOTAL USE, WESTERN SAN BERNARDINO COUNTY

Crop	Acreage	Estimated irrigation	Rain	Evapo-transpi-ration	Runoff and percolation	Total water application	Total water loss
		acre-inches per acre				acre-feet	
Citrus							
Sprinklers	5,570	50	17.8	31.8	36.0	31,470	16,710
Surface	3,000	54	17.8	31.8	40.0	17,949	10,000
Avocado	24	50	17.8	33.4	34.4	136	69
Walnuts	357	30	17.8	28.3	19.5	1,422	580
Deciduous	403	48	17.8	31.3	34.5	2,206	1,159
Grapes	10,509	12	17.8	21.2	8.6	26,094	7,524
Alfalfa	3,345	60	17.8	54.3	23.5	21,686	6,550
Sudan Silage	3,845	39	1.9	20.3	20.6	13,104	6,602
Pasture	3,764	54	17.8	51.1	20.7	22,520	6,493
Dry Beans	135	36	0.7	21.5	15.2	413	171
Strawberries	90	77	17.7	31.7	63.0	710	472
Lettuce, endive,							
carrots, burdock	75	33	17.1	16.1	34.0	313	212
Cabbage, broccoli,							
cauliflower	60	33	17.1	18.8	31.3	250	156
Corn, leek, beets,							
cantalopues	446	30	1.9	21.8	10.1	1,186	376
Onions, dry	367	60	8.0	27.2	40.8	2,080	1,248
Turf							
commercial	450	60	17.8	47.3	30.5	2,888	1,144
domestic	2,088	48	17.8	47.3	18.5	11,448	3,220
Totals	34,528					155,875	62,686

Table 15

ANNUAL WATER APPLICATION, AND TOTAL USE, WESTERN RIVERSIDE COUNTY

Crop	Acreage	Estimated irrigation	Rain	Evapo-transpi-ration	Runoff and percolation	Total water application	Total water loss
		acre-inches per acre				*acre-feet*	
Citrus							
Sprinklers							
new plantings	6,500	30	11.0	31.9	9.1	22,208	4,925
old plantings	4,540	40	11.0	31.9	19.1	19,308	7,240
Surface	13,518	42	11.0	31.9	21.1	59,691	23,765
Avocados	387	40	11.0	33.5	17.5	1,645	564
Walnuts	48	54	11.0	28.7	36.3	300	145
Deciduous	45	40	11.0	31.9	19.1	191	72
Grapes	1,368	18	11.0	21.5	7.5	3,306	355
Alfalfa	2,313	48	11.0	54.2	4.6	11,371	925
Pasture	4,120	54	11.0	51.0	14.0	22,314	4,808
Silage corn Sudan	1,914	42	1.7	20.6	23.1	6,969	3,684
Dry Beans	960	36	0.6	22.0	14.6	2,928	1,168
Strawberries	26	77	10.7	32.0	55.7	192	121
Cereals: grain	2,395	9	7.6	23.9	−7.3	3,312	
hay	2,554	9	3.5	10.2	2.3	2,659	488
Cabbage	704	33	9.6	17.7	24.9	2,499	1,461
Onions: Dry	140	60	5.9	33.1	32.8	769	383
Green	603	36	7.4	15.1	28.3	2,180	1,422
Lettuce	172	30	9.6	16.0	23.6	568	338
Corn, sweet	72	36	1.7	25.4	12 3	226	80
Melons	83	36	1.7	19.2	18.5	261	128
Miscellaneous	620	36	2.5	25.4	13.1	1,989	676
Turf							
commercial	850	60	11.0	47.2	23.8	5,029	1,686
domestic	2,618	48	11.0	47.2	11.8	12,870	2,573
Totals	46,550					182,785	57,007

to these continuing heavier irrigation applications are the increased use of Colorado River water in Riverside County, and increased awareness of salinity problems. Total applications and losses are amplified by the winter rainfall. From many years of recurrent drought since 1950, growers have learned to continue irrigation practices for permanent crops during fall and early winter months until rains actually arrive in substantial amounts. In dry years, irrigation continues all winter. In wet years, rainfall is extra, and that not lost by surface runoff serves mainly to aid in leaching salt from the soil.

Partition of losses between surface runoff and deep percolation is highly imprecise from available information. Table 16 shows estimates for citrus and turf, two of the main contributors to water loss. Reduction of total water applied might be expected as water costs increase and irrigation methods improve (awareness of salinity hazards has temporarily diminished the potential gain). Changes in citrus acreage have altered total water application and losses in this basin (table 17). Future increases in water costs and improved irrigation techniques may lead to reduced water use, but this will have little effect on total nitrate contributions to underground and surface waters. Concentrations of nitrogen leached downward are affected directly by the quantity of water, but the total quantity of nitrogen moved remains nearly constant. Changes in nitrogen are therefore more likely to be affected more by changes in crop acreages and fertilizing practices than by changes in irrigation management.

Most of the water applied and most of the losses to the underground in the Upper Basin are contributed by three cropping systems: citrus, turf, and the

Table 16

ESTIMATE OF ANNUAL WATER LOSSES AS SURFACE RUNOFF FOR CITRUS AND TURF

Area, crop, and type of irrigation	Irrigation	Rain	Total	Runoff percentage	Annual runoff	Annual percolation
	acre-inch per acre			*per cent*	*acre-feet*	
San Bernardino, east						
Citrus: Sprinklers	2.7	3.4	6.1	17	1,347	6,578
Surface	9.0	2.7	11.7	28	12,614	32,080
Turf: Commercial	6.0	2.0	8.0	30	561	1,309
Domestic	4.8	2.0	6.8	47	2,431	2,742
				Total	16,953	42,709
San Bernardino, west						
Citrus: Sprinklers	2.5	4.5	7.0	19	3,174	13,536
Surface	8.1	3.6	11.7	29	2,900	7,100
Turf: Commercial	6.0	2.7	8.7	28	320	824
Domestic	4.8	2.7	7.5	40	1,288	1,932
				Total	7,682	23,392
Riverside, west						
Citrus: Sprinklers (new plantings)	2.0	2.8	4.8	53	2,600	2,325
Sprinklers (old plantings)	2.0	2.8	4.8	25	1,815	5,425
Surface	6.3	2.2	8.5	40	9,506	14,259
Turf: Commercial	6.0	1.6	7.6	32	540	1,146
Domestic	4.0	1.6	5.6	47	1,209	1,364
				Total	15,670	24,519

Table 17

ANNUAL APPLICATION AND LOSS FOR CITRUS, WESTERN RIVERSIDE COUNTY, 1930–1970*

Year, and type of irrigation	Acreage	Estimated irrigation	Loss	Total application	Total loss
		acre-inches per acre		*acre-feet*	
1930					
Sprinklers	0				
Surface	19,339	42	21.1	85,401	33,998
	Total 19,399			85,401	33,998
1940					
Sprinklers	0				
Surface	20,126	42	21.1	88,876	35,382
	Total 20,126			88,876	35,382
1950					
Sprinklers	1,773	36	15.1	6,943	2,230
Surface	16,375	42	21.1	72,312	28,787
	Total 18,148			79,255	31,017
1960					
Sprinklers	2,212	42	21.1	9,768	3,889
Surface	15,445	40	19.1	65,641	24,573
	Total 17,657			75,409	28,462
1970					
Sprinklers					
new plantings	6,500	30	9.1	22,208	4,925
old plantings	4,543	40	19.1	19,308	7,240
Surface	13,513	42	21.1	59,691	23,765
	Total 24,561			101,207	35,930

* Annual rain = 11.0 inches; annual ET = 31.9 inches.

crops closely associated with the dairy industry—alfalfa, pasture, and silage.

Water use for citrus. Evapotranspiration (ET) estimated for citrus is nearly the same in San Bernardino County as in the Riverside citrus areas, though leaching losses are considerably greater in the former. The reason may be related to the more permeable soils and lower water costs in the San Bernardino area. The ET in both these citrus areas as reported is about 32 inches per year (Blaney-Criddle formula), but water applications indicate efficiencies of about 44 per cent in San Bernardino (Bunker Hill Sub-basin) and 60 per cent in the Riverside area. Water not used in evaporation or transpiration is lost by runoff or by deep percolation into the underground.

Total water applied in the San Bernardino citrus area is about 71 inches (irrigation plus rainfall), of which 39 inches is in excess of ET. It is estimated that 29 inches of this excess goes to deep percolation within the groves and that as much as 10 inches may run off to surface drains. In the Riverside citrus area there is a total of about 49.5 inches of irrigation and rainfall, of which 17.5 inches is in excess of crop needs (ET). An estimated 10.5 inches is lost to deep percolation, and 7 inches to runoff.

The above facts apply mostly to surface irrigation. Sprinkler irrigation could reduce these losses, but savings in water from sprinklers presently used by most growers are not as great as might be expected, although some improvement in application efficiency has been made in newer citrus plantings. Most new citrus in Riverside County has been planted on sloping upland soils that are generally rather shallow and irrigation is almost entirely by sprinklers under careful supervision. The trees are still young so water use is expected to increase as trees get larger. Average use at 6 years was 27.5 inches per year (at 5 years the same trees used only about 22 inches). Plotted curves suggest that at maturity applications should be about 35 inches. Total application on these new plantings would be 46 inches (irrigation plus rainfall) as compared to the current 49.5 inches as reported for all acres.

Water use for alfalfa, silage, and pasture. These show an average annual water application of about 50 inches of water. plus 14 inches from rainfall. The water balance of the crops indicates that about 17 inches of water are applied in excess of ET, with perhaps 12 inches going into deep percolation.

Water use for turf. On the average, turf also is irrigated with about 50 inches of water; this plus 14 inches of annual rainfall accounts for 17 inches in excess of crop needs, of which an estimated 10 inches will go into deep percolation and 7 inches to runoff.

NITRATE CONCENTRATIONS IN SOIL PROFILES IN RELATION TO AGRICULTURAL PRACTICES

Removal of fertilizer nitrogen by crops is generally reported to be inefficient. Uptake of applied nitrogen is frequently 50 per cent or less. Most of the nitrogen not removed by crops is believed to be leached below the root zone by rainfall or irrigation water, or lost by denitrification. The concentration of nitrate in soil water which percolates downward and eventually becomes groundwater is influenced by many factors, including nitrogen and water inputs to the system, soil physical characteristics, removal of nitrogen in harvested crops, denitrification, and ammonia loss from manures, etc. Estimation of the nitrate concentration of percolating water is therefore complex. Only in the last few years has research been directed toward developing techniques for making such estimates. This work has involved deep borings and soil sampling by incremental depths in areas where available data on management history are reasonably reliable.

Nitrate in soil solution below citrus. Until recently the main reason for meas-

uring leaching of nitrate below the effective rooting depth of crop plants was the loss of nitrate to the crop, with consequent loss of production or a need for more fertilizer nitrogen to adjust for losses. With a tremendous increase in concern about nitrate in both surface and groundwaters in the last few years, the emphasis has changed to the study of nitrate leaching in relation to the potential pollution of waters. Accordingly, a study was recently made to determine the potential contribution of citrus fertilization to the nitrate in groundwater. The data acquired in this study were used to develop equations which could provide estimates of nitrate concentrations in the unsaturated zone between the zone of root influence and the saturated zone. The important factors are: the volume of drainage water (which is obtained if the leaching fraction and evapotranspiration are known, or can be estimated as total water input minus evapotranspiration), and the yearly excess of nitrate available for leaching (which can be obtained from fertilizer rates minus removal in harvested crops).

Sites were selected for sampling of deep-soil profiles under a wide range of nitrogen fertilization rates, and included some differences in physical conditions of soils. Some sites were located in a long-term fertility trial with Washington navel oranges where nitrogen had been applied annually at rates ranging from 50 to 550 pounds per acre from 1927 to 1962 and at a uniform rate of 150 pounds per acre thereafter. Other sites were in four commercial groves, where fertilizer nitrogen applied in the period 1950–69 varied from about 140 to 170 pounds per acre per year. Depth of sampling was 100 feet in the fertility trial sites, and 50 feet or to the top of the water table in the commercial groves.

Analysis of the samples showed that nitrate concentration in the soil solution below the root zone increased with increasing rates of nitrogen fertilization. For example, in a program of low nitrogen fertilization (150 pounds per acre per year) concentration in the soil solution below the root zone was 84 ppm nitrate, in contrast to 198 ppm nitrate for the highest rate of nitrogen fertilization (350 pounds per acre per year) at a leaching fraction of 0.41. In general, higher nitrate levels were associated with lower leaching fractions.

Estimates of nitrate concentrations in soil water made with the equations mentioned above were found to be reasonable for porous open soils when inputs of nitrogen were about 135 pounds per acre per year. However, at higher input rates —or at low rates with soils having profiles containing textural discontinuities—significant levels of denitrification had to be assumed to obtain a reasonable nitrogen balance. Since all factors except denitrification were known to a reasonable degree of accuracy in this study, denitrification was estimated as the unaccounted-for losses.

Rates of nitrogen applied usually vary from 100 to 150 pounds per acre per year. These rates, combined with high production and leaching fractions of 0.35 or more, should lead to a drainage water having a nitrate content of 88 ppm or less. Thus, orange growers in southern California seem to have adjusted their fertilizer inputs to levels that do not leave in the drainage water a nitrate load considered serious by present California policy (which permits nitrate levels up to 90 ppm; drinking-water standards set by the U. S. Public Health Service require less than 45 ppm of nitrates).

The study also made possible some estimates of the transit time for leaching water and accompanying nitrate to pass through the unsaturated zone (Pratt *et al.*, 1972). Transit times through this zone suggest that the excess nitrogen in a surface soil in any one year might not be a contributor to nitrate in well waters until many years in the future. If the transit distance is 100 feet, a time lag of 10 to 50 years is likely in the alluvial materials studied in the Upper Santa Ana River Basin.

Nitrate in soil solution below vegetable crops. Additional field samples were taken for investigation of nitrate concentrations in water percolating downward under vegetable crops. Some differences might be expected from the orange data because nitrogen fertilization rates are generally higher for vegetable crops. Nevertheless,

Table 18

AVERAGE NITRATE CONCENTRATION IN SOIL PROFILES UNDERNEATH AREAS USED FOR VEGETABLE CROP PRODUCTION

Site number	Site location and description*	Average N application	Average amount irrigation water	Average nitrate concentration in: saturation extracts (0-to-8-feet depth)	Average nitrate concentration in: soil water (11-to-50-feet depth)
		lb. per acre per year	*acre-feet per acre per year*	*ppm*	
1-A	South Coast Field Station Asparagus Moreno sandy loam	500 (1962–69)† NO N (1970–71)	1.5 (1962–67)† 1.75 (1967–71)	34	439
1-B	Same as site 1-A	100 (1962–69) NO N (1970–71)	1.5 (1962–67) 1.75 (1967–71)	26	38
1-C	Same as site 1-A	500 (1962–69) NO N (1970–71)	2.5 (1962–67) 1.75 (1967–71)	62	150
1-D	Same as site 1-A	100 (1962–69) NO N (1970–71)	2.5 (1962–67) 1.75 (1967–71)	26	65
2-A	South Coast Field Station Celery-cabbage Moreno sandy loam	180 (1958–64) NO N (1965–66) Fallow (1967–70)	6 (1958–66)	103	212
2-B	Same as site 2-A	540 (1958–64) NO N (1965–66) Fallow (1967–70)	6 (1958–66)	158	259
2-C	Same as site 2-A	1,740 (1958–64) No N (1965–66) Fallow (1967–70)	6 (1958–66)	318	374
3	South Coast Field Station Strawberry-barley Moreno sandy loam	100 (1962–71)	3 (1962–71)	68	235
4	Marshburn Farms, Irvine Celery-sweet corn Ramona loam	1,205 (1966–70)	6 (1966–70)	232	525
5	Yamano Farms, Home Garden Misc. vegetables Chino silty loam	431 (1960–70)	5 (1960–70)	119	322
6	U.C. Field Station, Moreno Sugarbeets-sorghum-grain Ramona sandy loam	380 (1961–72)	2.25 (1961–71)	122	264
7	U.C. Field Station, Moreno Sugarbeets Hanford loamy sand	380 (1961–71)	2.25 (1961–71)	83	247
8	Marshburn Farms, Moreno Carrots-melons Hanford loamy sand	442 (1968–70)	2.5 (1967–70)	220	241
9	McSweeny Ranch, Hemet Potatoes-barley-wheat Hanford loamy sand	200 (1960–70)	2.6 (1960–70)	97	175
10	Anderson Ranch, Chino Potatoes-sweet corn Chino silty loam	431 (1960–71)	2.3 (1960–70	539	536
11	Borba Ranch, Chino Potatoes-barley-sweet corn Hillmar sandy loam	273 (1959–71)	3.2 (1959–71)	113	336

* Soil types tentatively identified.
† Numbers in parentheses refer to years applied.

Table 19

THEORETICAL NITRATE CONCENTRATIONS (in ppm) FOR VARIOUS COMBINATIONS OF DRAINAGE WATER AND NITROGEN

Inches of drainage water	Parts per million of nitrate percolating downward when various amounts of drainage water combine with various weights of N available for leaching*					
	Weights of N					
	10 lb.	20 lb.	40 lb.	60 lb.	80 lb.	100 lb.
2	98	196	392	588	784	980
4	49	98	196	294	392	490
6	33	65	131	196	261	327
8	24	49	98	147	196	245
10	20	39	78	118	157	196
12	16	33	65	98	131	163
14	14	28	56	84	112	140
16	12	24	49	74	98	122
18	10.8	22	44	65	87	109
20	9.8	20	39	59	78	98
22	8.9	18	36	53	71	89
24	8.2	16	33	49	65	82
26	7.5	15	30	45	60	75
28	7.0	14	28	42	56	70
30	6.5	13	26	39	52	65
32	6.1	12	24	37	49	61
34	5.8	11.5	23	35	46	58
36	5.4	10.9	22	33	44	54
38	5.2	10.3	21	31	41	52
40	4.9	9.8	20	29	39	49
42	4.7	9.3	19	28	37	47
44	4.5	8.9	18	27	36	45
46	4.3	8.5	17	26	34	43
48	4.1	8.2	16	24	33	41

* Thus 2 inches drainage water and 10 lb. N available for leaching results in 98 ppm nitrate *etc.*

Note: Calculated from formula:

$$C = \frac{19.6\ \mathrm{N}}{D_w}$$

C = nitrate concentration in parts per million in drainage water.
19.6 = constant from conversion of N to NO_3 and inches of drainage water to pounds per acre-inch of D_w.
N = nitrogen available for leaching in pounds per acre.
D_w = inches of applied water plus rainfall draining below recovery by roots.

factors such as water use, denitrification, crop removal of nitrogen, etc., also influence nitrate concentration in soil water, so field data are needed for vegetable crops rather than relying on extrapolation of orange data.

Table 18 gives nitrate concentrations found in samples from the soil profile taken from 16 sites cropped to vegetables in the Santa Ana Basin in the spring of 1971. Nitrogen fertilization rates ranged from 100 to 1740 pounds per acre per year, and irrigation water applied averaged from less than 2 to 6 acre-feet per acre per year. As nitrogen fertilization rate increased up to about 600 pounds per acre per year, average nitrate concentration at depths of 11 to 50 feet tended to increase. The data show, however, that factors other than nitrogen fertilization rates also influence nitrate concentrations in the soil water. The average nitrogen fertilization rate for vegetable crops in the Basin is now about 180 pounds of nitrogen per acre. When a vegetable crop is fertilized at that rate, roughly 100 pounds of nitrogen per acre is unaccounted for in the crop (data supplied by Takatori and Lorenz). This results in considerable opportunity for deep percolation of nitrates to underground waters.

Concentration of nitrates in drainage water below crops will vary with the quantity of water percolating downward

and with the amount of nitrogen available for leaching. Table 19 shows theoretical concentrations of nitrate for various combinations of drainage water and nitrogen. For example, with 100 pounds of nitrogen available for leaching, 12 inches of drainage will give a solution with 163 ppm of nitrate percolating downward. With 24 inches of drainage water, the nitrate concentration is reduced to 82 ppm.

For the over-all Upper Santa Ana Basin (356,000 acres) vegetables were planted on about 2.7 per cent of the acreage in 1930 and about 1.4 per cent in 1969. We conclude that the contributions of nitrates from fertilizers used on vegetable crops will not substantially affect the over-all quality of groundwater, except perhaps in those localized areas where vegetable acreage may be concentrated.

As to the crops in areas producing well waters of high nitrate content, the Middle Chino Sub-Basin was predominately field crops, vegetables, and alfalfa in 1930, with an estimated 20 to 25 per cent of the acreage planted each year to vegetables (mostly potatoes). In 1930, vegetables were not an important crop in the Bunker Hill Sub-Basin study area or the Riverside, Arlington, and east Pomona areas.

AMOUNTS OF NITRATE IN SOIL WATER AND GROUNDWATER UNDER DAIRY FARM AREA, CHINO-CORONA SUB-BASIN

In areas having high-density cow populations, wastes are often placed on lands for disposal purposes rather than for fertilization. This is a common practice in the Chino-Corona dairy area, which has a cow population of more than 122,000. Thus with only about 12,500 irrigated acres available for disposal, the average ratio of cow to disposal acre is about 10:1. Wastes are confined either in corrals, adjacent croplands, or adjacent pastures. Groundwaters underneath these areas can be polluted with nitrate when application rates of manure supply nitrogen in excess of crop needs. Leaching of nitrate is increased by irrigation management appropriate to maintaining a suitable salt balance in the soil-crop environment.

To assess the contribution of dairy farming to nitrate contamination of the soil water and the groundwater, soil and groundwater samples were collected from 27 locations, to a depth of 19 feet or to the top of the water table. Included were nine corral, nine pasture, and nine cropland sites. Application rates of manure on the cropland sites varied from 20 to 45 tons per acre per year. Detailed results of these studies are published elsewhere Adriano *et. al.*, 1971*a*, *b*).

The amount of nitrate varied widely between sites. On the average, the total nitrogen per acre for the profiles of 19-foot depth was 1,938 pounds for corral, 670 pasture, and 727 for cropland.

Nitrate contributions by disposal practices can be evaluated from concentrations in the soil water in the unsaturated zone at depths below the reach of the root systems. At these depths the nitrate cannot be absorbed by roots and recycled by the crops; if not denitrified to gaseous nitrogen, this nitrate will be leached to the groundwater. Average concentrations of nitrate in the soil water at a depth of 10 to 19 feet were respectively 405, 326, and 290 ppm for the corral, pasture, and cropland sites. The respective waters from the top of the water table, however, averaged nitrate concentrations of 251, 326, and 198 ppm. Well waters pumped from deeper aquifers in the vicinity of the sites averaged 26 ppm of nitrate, well below California's recommended limit. The data suggest that disposal practices have not yet had a full impact on the water table, particularly in the case of the corral sites. Many operators know that high rates of nitrogen input can result in sufficient nitrate accumulation in crop-tissues to cause poisoning of livestock, but only recently have data been made available on nitrate leaching beneath such areas.

Table 20

TOTAL N INPUT IN SOILS, REMOVAL BY CROPS, EXCESS IN THE SOIL, AND CALCULATED NITRATE CONCENTRATION IN THE SOIL WATER IN UNSATURATED ZONE, ASSUMING TWO LEVELS OF LOSS OF EXCESS N

Number of cows per disposal area	Total N excreted (all cows)†	Amount of N incorporated in soil	Amount of N removed by crops‡	Excess N in soil	Nitrate in unsaturated zone assuming§: 0 per cent loss of excess N	Nitrate in unsaturated zone assuming§: 25 per cent loss of excess N
	lb. per acre per year				*ppm*	
3	438	219	190	29	37	28
4	584	292	240	52	67	51
5	730	365	270	95	123	92
6	876	438	290	148	192	144
8	1,168	584	320	264	342	256
10*	1,460	730	350	380	492	369
12	1,752	876	370	506	654	491
14	2,044	1,022	380	642	830	622

* The values for the N rate equivalent to the 10-cow level were based on 200 pounds N removal by 30 tons per acre of corn silage plus 150 pounds N removal by 4 to 5 tons per acre of green crops. In all cases, double cropping was assumed.

† Assuming that each cow defecates 0.40 pounds N per day.

‡ Figures based on published data and field data of Extension Specialists in the area.

§ In soil water in aerated zone below the root system, assuming the drainage volume to be 15 surface inches per year.

Table 20 shows a typical nitrogen balance sheet for estimating the average nitrate concentration in soil water leaving the root zones under pastures and croplands. One-half of the nitrogen excreted is assumed to volatilize as ammonia, and the other half is incorporated into the soil. (Our analysis showed about 38 per cent total nitrogen loss from corral manures, but more losses can be expected after land application.) The excess in the soil is the amount incorporated into the soil minus removal by crops. The rough estimates are the volume of drainage water, and the extent of denitrification and mineralization rate, which represent losses not otherwise accounted for. The drainage volume used was 15 inches, which corresponds to an average leaching fraction (LF) of about 0.30, which is a common value for successful irrigation management. (Leaching fraction is the volume of water that moves past crop-root systems, expressed as a fraction of the total irrigation water used.) The values for the 25 per cent loss column were calculated on the assumption that one-fourth of the excess nitrogen is nitrified and then denitrified. Compared with some of the published data this assumption seems reasonable (Pratt *et al.*, 1970; Tisdal and Nelson, 1966).

Average nitrates in soil water at depths of 10 to 19 feet under the pasture and cropland sites were respectively 326 and 290 ppm. The concentrations, however, ranged from 106 to 896 ppm in pastures and from 66 to 931 ppm in croplands. Only 3 of the 18 sites had a nitrate concentration of 90 ppm or less in soil water at this depth. These variations were obviously due to differences in disposal rates, crop removal, leaching losses, and denitrification. Comparing these data with data in table 19 we can see that some of the rates apparently exceeded the equivalent of 14 cows per acre.

GUIDELINES FOR MINIMIZING NITRATE IN GROUNDWATER

Nitrogen reaching underground water supplies of the Upper Santa Ana River Basin can come from several possible sources, but any significant contributions from agriculture are likely to be associated mainly with crop fertilization and waste disposal. The following section suggests methods for reducing the amount of nitrate pollution from agricultural sources.

Fertilization

Rates of fertilization. In the Upper Santa Ana Basin, naturally-occurring soil nitrogen reserves are too low to produce crop yields high enough for sustained commercial agricultural production. Except with legume crops, which utilize atmospheric nitrogen through conversion by legume bacteria living on their roots, supplemental fertilizer nitrogen must be applied to all crops if agriculture is to continue in the Basin. Rates of nitrogen application required for good yields and good quality vary from crop to crop. Citrus and vegetables are crops to which nitrogen is applied at rather high rates; this can, under inefficient management, result in excessive nitrogen additions to the underground water supply.

Citrus is the major crop of the Basin. Nitrogen fertilization rates prior to 1960 were about 300 pounds per acre or more, but growers have been able to reduce these rates to 100 to 150 pounds per acre from all sources (fertilizer, manure, nitrogen in irrigation water, etc.), thanks to improvements in diagnostic tools for predicting nitrogen needs (plant-tissue analysis). The current recommendation on citrus is to use leaf analysis as a guide to nitrogen fertilization and to apply the fertilizer in one application in the winter. Leaf analysis integrates the effects of many factors into one figure—i.e., the nitrogen concentration in a specific type and age of leaf. These guides were developed to permit maximum yield at lowest cost, so the great reduction in pollution potential is an extra benefit. A further reduction in the suggested optimum nitrogen level in leaves might improve the fruit quality of oranges and further reduce the pollution potential. Such a program is likely to reduce yields slightly, but that might be counterbalanced by improved fruit quality. Experimental and preliminary results from the Delano, California, citrus area indicate that a new fertilization procedure—foliar fertilization—may offer good possibility for maintaining acceptable yields of high-quality fruit at greatly reduced levels of soil nitrogen, and with a greatly reduced potential for nitrate pollution of underground waters.

As to vegetables, here again soil reserves of nitrogen in the Upper Santa Ana Basin are too low for satisfactory vegetable crops to be produced without rather large additions of nitrogen. Field experiments indicate that maximum yields under cropping practices usual to the area will require 120 to 300 pounds of nitrogen per acre applied in two or more applications, the rate varying with the crop. Grower practice on the average is to apply higher amounts than this. The text-table on page 30 shows typical rates of nitrogen which have produced near-maximum yields of crops in the Santa Ana Basin.

Field crops, noncitrus fruit crops, and turfgrass are not heavily fertilized and apparently do not contribute appreciably to nitrogen problems in underground waters of the Basin.

Timing fertilizer applications to match needs of crops. For annual crops (vegetables and field crops) split applications of fertilizers are to be encouraged—one-fourth to one-half of the nitrogen needs of the crop applied at or near planting time, and again at the time of most rapid growth. Fertilizing of tree crops or spring-planted annual crops in late summer and fall is inefficient, and excessive deep percolation losses of nitrogen to underground water supplies may result from rainfall and normal fall-winter irrigations, or from irrigations made in preparation for planting. The most critical period for tree crops is generally bloom time. To ensure maxi-

mum yields a single nitrogen application, timed sufficiently ahead of bloom to assure high nitrogen at bloom, is recommended. High nitrogen concentrations in the plant at bloom will usually be enough to supply crop needs for the rest of the season.

Slow-release fertilizers. Relatively new, slow-release fertilizers offer interesting possibilities of reducing nitrogen losses below crop root zones by releasing nitrogen at rates that match crop needs more closely. Some promising materials have been developed recently, but in general their use is still experimental. Adequate results from slow-release fertilizers must wait for improvements in formulations and for more extensive field testing.

Animal manures can be thought of as a form of slow-release nitrogen. About one-half the nitrogen in manures is released during a cropping period of 2 to 3 months.

Recommendations for use of manures usually include the following:

- apply well ahead of planting
- disc or otherwise incorporate the manure at least 6 inches into the soil
- irrigate adequately to leach detrimental salts away from germination zone of the crop to be planted
- a light supplemental nitrogen application may be needed near planting time if crops are planted in the cool season, since nitrogen release from manure is slower in cool weather
- do not apply bulk manure to growing crops, because of plant disease problems, fly problems, and other undesirable effects
- to reduce deep percolation losses, disposal of dairy washwater or waste effluent by irrigation (either surface ditch, pipe, or sprinkler) should be timed to apply quantities consistent with crop or soil requirements for water and nitrogen.

Soil analysis or plant-tissue analysis, or both, can be helpful in timing applications by evaluating nitrogen needs or crop response to nitrogen application at a given time. Soil samples (or soil solutions extracted by soil-solution probes) taken below crops can be analyzed to evaluate nitrogen losses resulting from various timings of fertilizer applications.

Water use

Nitrates are 100 per cent water-soluble. The total amount of nitrogen reaching underground waters is important, but the main concern of this study has been the concentration of nitrate-nitrogen and the high concentration that is now evident in groundwaters of certain areas. Concentration of nitrate in soil water can be varied by changing either the quantity of nitrogen or the volume of water applied.

The objective in the guidelines to fertilization has been to reduce nitrogen rates consistent with satisfactory crop yields or consistent with a product of acceptable quality. Control of nitrogen pollution may require not only reduced rates of fertilization but, also, application of enough water in excess of crop needs so that waters percolating downward will dilute nitrogen to a more acceptable concentration. Citrus, however, is susceptible to increased disease from over-irrigation, thus limiting use of this method.

Crop needs for water. Evapotranspiration (ET) can be calculated from various semi-empirical formulae, measured indirectly by various types of devices such as evaporation pans, or measured more directly by lysimeters. Effective rainfall must be included in calculations of the water supplied to fulfill the ET needs of a crop; these ET values may be used as a guide to crop needs and as a measure of efficiency of irrigation. ET has been estimated for the crops grown in the Upper Santa Ana Basin (see tables 13, 14, 15); these estimates may also be used as a guide to calculate irrigation efficiency, and as a base from which to estimate probable quantities of percolating water moving nitrates downward.

Leaching fraction. Another way of estimating the quantities of water moving downward is based on the leaching fraction. A leaching fraction of 0.20 to 0.50 is common (20 to 50 per cent of the water entering the soil percolates beyond the reach of roots and becomes drainage water). The leaching fraction for well-drained soils may also be estimated more directly by comparing the concentration of a constituent such as chloride in the irrigation water with the chloride in the

soil solution below the root zone. For example, if chlorides in the soil solution below the root zone are 5 milli-equivalents per liter, and the chlorides in the applied water are 2 milliequivalents per liter, the leaching fraction is $\frac{2}{5} = 0.40$, or 40 per cent.

Waste disposal

For preventing or reducing the pollution of soil or water by animal wastes within a watershed such as the Upper Santa Ana Basin, three basic criteria are suggested:

- prevention of runoff into surface waters or intrusion into groundwaters
- recycling of waste nutrients through soil-plant systems or through refeeding techniques
- disposal or export of surplus solids which cannot be safely recycled within the basin.

Prevention. Present practices of handling wastes from people and animals appear inadequate, as evidenced by the nitrate content of surface waters of the Santa Ana River at Colton, Riverside Narrows, and Prado Dam, by the nitrate content measured in percolating waters moving below land-disposal areas of the Chino dairy area, and by excessive nitrate content of the upper portions of underground water supplies of the Chino area underlying these land-disposal sites.

Prevention might include one or more of the following items:

- reducing waste loadings per disposal acre. Results of studies in the Chino area, as presented in table 20, offer some guidelines to dairy waste disposal—similar tables can be prepared by varying the assumptions, such as higher or lower quantities of water percolating to the water table. The assumptions used and the projected results in terms of nitrates expected in the percolating waters are in reasonable agreement with published data
- using these tabular data, to keep nitrates in the percolating waters at 90 ppm or less (assuming excellent management) the disposal rate must be adjusted to about 4 to 5 cows per acre. To lower the nitrates to 45 ppm, no more than 3 cows per disposal acre can be accommodated
- using preliminary treatment of nitrogenous wastes to reduce nitrogen by utilizing nitrification-denitrification processes, either in temporary holding ponds or by land disposal to soil areas especially suited for this purpose
- controlling manure-laden runoff from land areas and areas where wastes accumulate by maintaining dikes and ponds or adequate storage capacity. Storage capacity to retain or control runoff from a 10-year probability storm is suggested. Waste materials collected behind dikes or within holding ponds would need to go to land disposal in a manner similar to disposal of other animal wastes
- requiring a satisfactory plan of disposal by each producer of wastes (i.e., a disposal that maintains a quality of surface runoff or percolating water that is within acceptable limits for nitrogen)
- zoning the entire watershed for pollution potential on the basis of soil characteristics as related to the ease with which nitrates can be leached to underground water basins, and restrict land usage to that consistent with the pollution potential
- relocating nitrogenous waste dischargers and/or disposal sites to areas where nitrate pollution of surface and underground water is minimal (present locations are at sites that are most favorable for rapid pollution of surface and underground water supplies)
- recharge of groundwaters with available water of good quality, particularly winter flood waters, should be beneficial in maintaining pressure within the aquifer and maintaining a diluting supply of low-nitrate water in the deeper underground. The hydrology of the basin, however, is such that changes in the general quality of underground waters due to injection or recharge with waters of better quality will be extremely slow (expected to take tens to hundreds of years).

Recycling of wastes. Recycling is being attempted in many management systems for waste disposal. The most usual recycling procedure is the recovery of nitrogen in a growing crop. On the acreage available for disposal, however, waste loadings are often greatly in excess of the

crops' capacity to utilize the nitrogen available. Points to consider in recycling are:

- a limited recycling of manure wastes by refeeding to livestock may soon become a practice, but is not yet of commercial importance
- recycling of the nitrate already in the underground is possible. Develop shallow wells for agricultural use to withdraw water from the upper portion of the underground water supply (i.e., the portion containing the highest concentration of nitrates), and recycle the nitrogen through crops
- development of deep wells for domestic use to draw water from the deeper low-nitrogen portion of the underground water supplies
- since waters move very slowly, consider utilizing (sacrificing) a portion of the underground basin as a disposal area for high-nitrogen waters. These stored high-nitrogen waters could then be utilized for irrigation by pumping, and the nitrogen utilized for fertilizing crops. This is similar to a groundwater recharge operation with recovery of both water and nitrogen for agricultural use
- **Disposal of animal wastes.** Rapid aerobic composting as a form of manure processing is well adapted to bulk handling and improves the usefulness and acceptability of the product by eliminating offensive odors and fly attraction. After composting, the processed manures can be exported or moved to remote areas for recycling. Bulk manure shipments for agricultural use outside of the basin may be expanded. Shipment of processed and bagged or dried organic fertilizers for organic gardeners and nursery trade, and sale of processed manure mulch for commercial landscaping, are present disposal opportunities which will remove nitrogen from the basin. Such disposal procedures should be encouraged since so few areas of irrigable land are available for in-basin recycling by land disposal and cropping.

A last resort for control of both nitrogen and salinity could be construction of an agricultural-industrial drain or sewage system for treatment, reclamation, and ultimate export of wastes from an entire basin (or portion).

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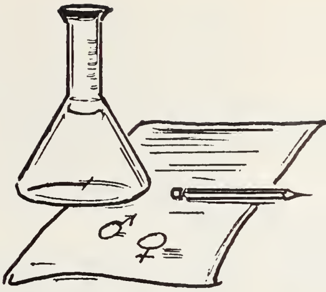

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Many experiments conducted in the laboratories by staff members of the Division of Agricultural Sciences show promise of benefiting crops or animals.

it may work here . . .

Laboratory findings are often given further tests under controlled conditions in greenhouses (new plant varieties, for instance).

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if it does . . . if field tests indicate higher yields, greater resistance to pests or disease, drought or moisture—if the development benefits mankind, the facts will be made available. Thus is science applied to agriculture by the

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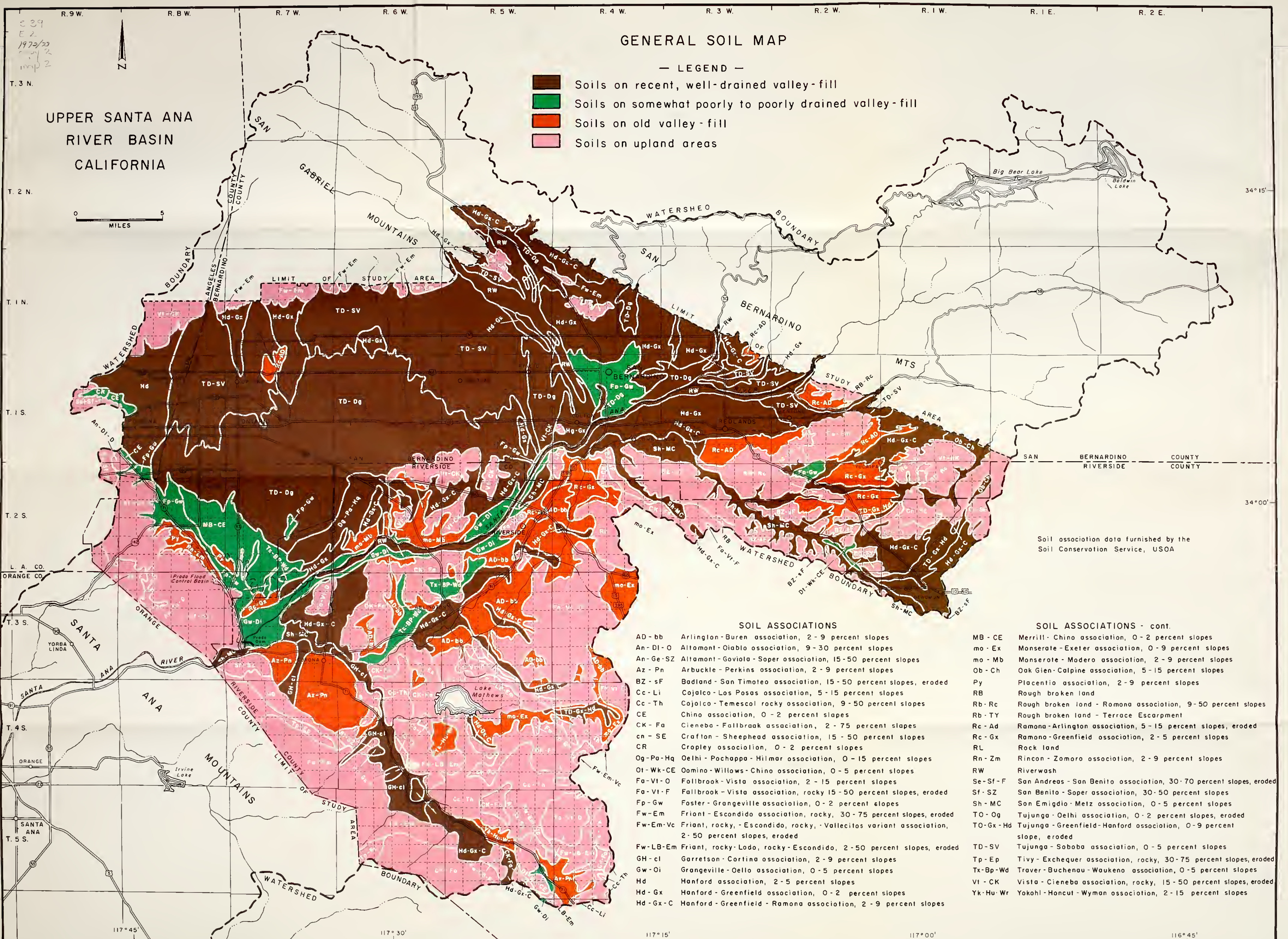
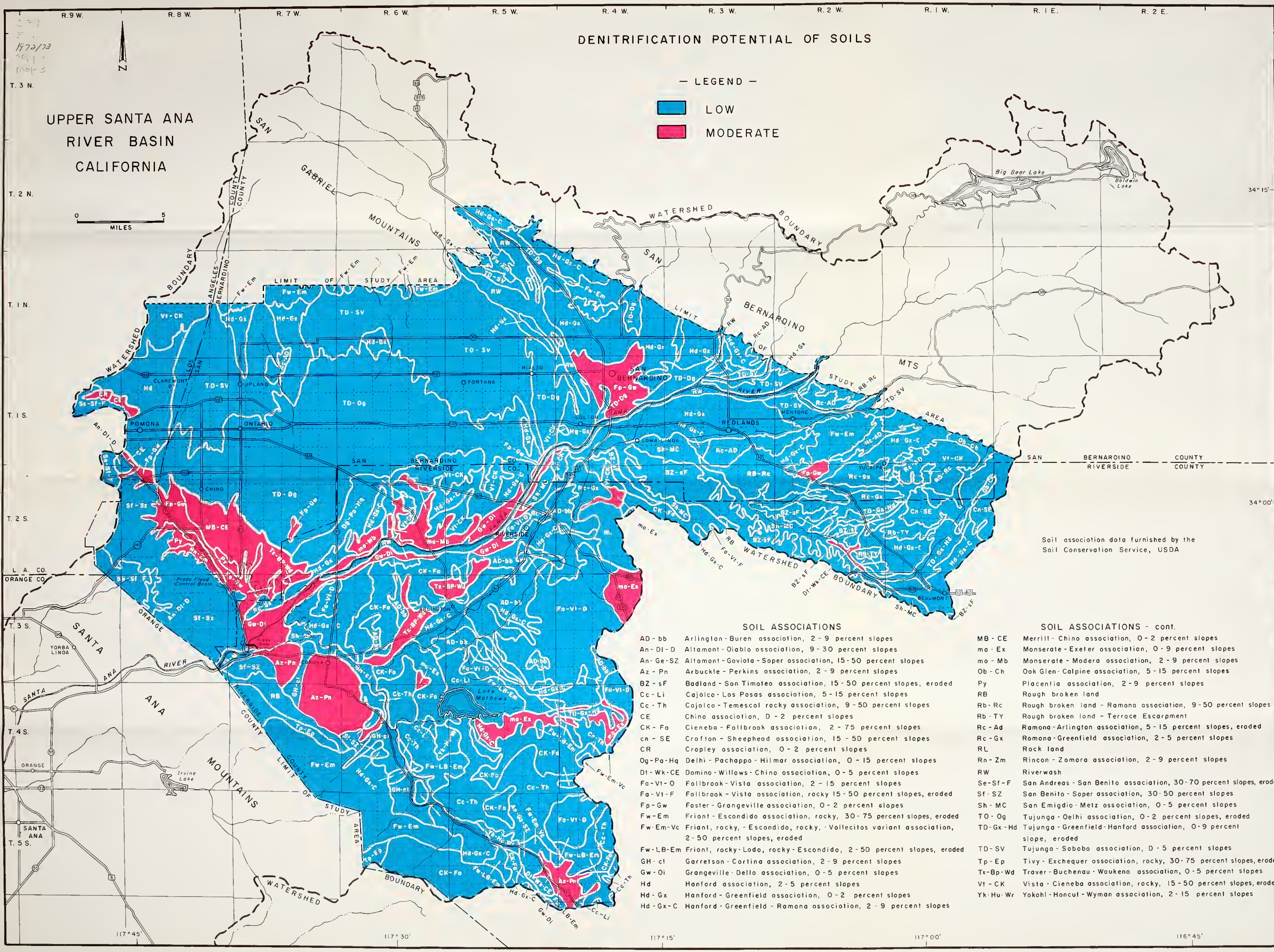
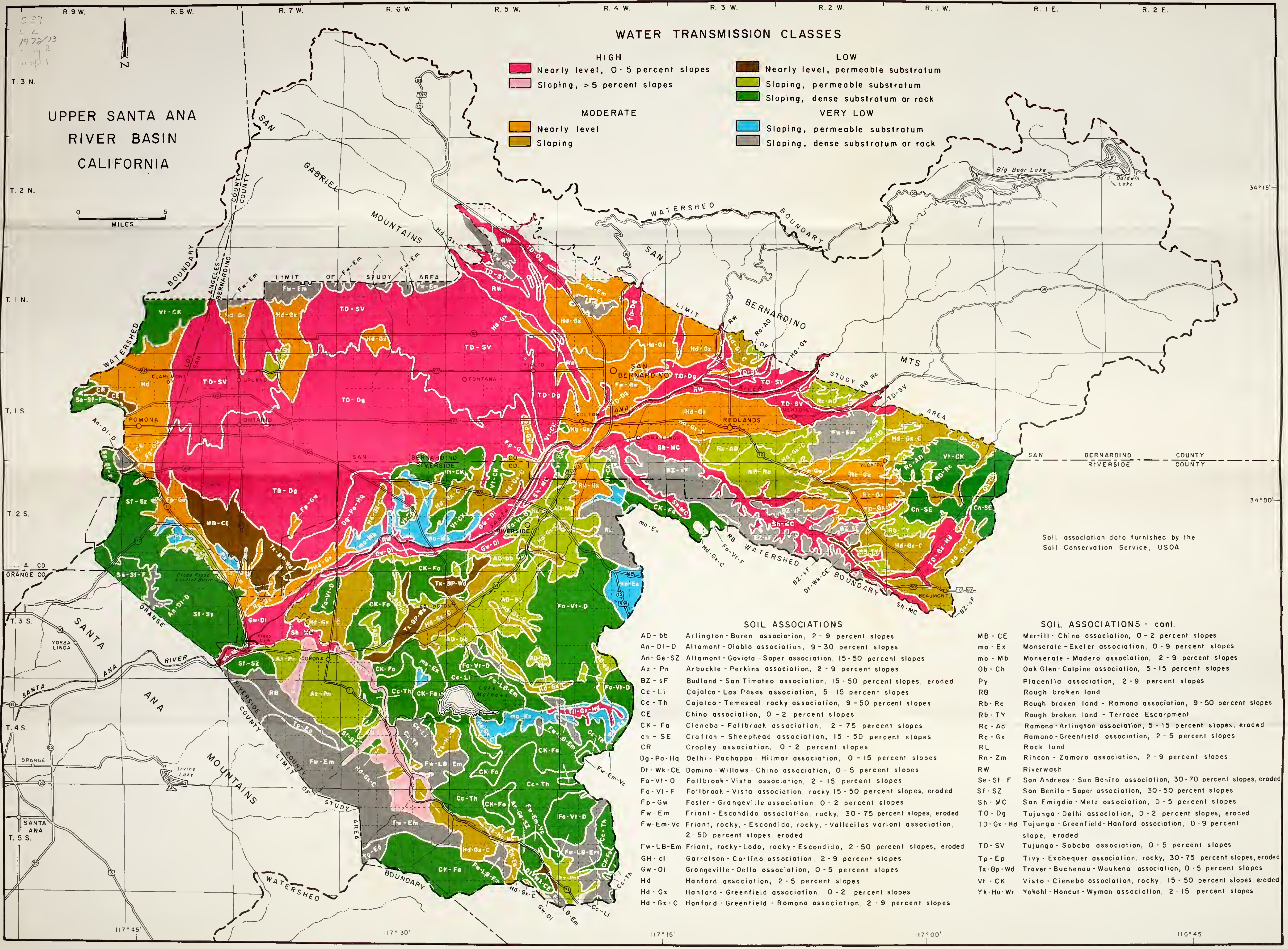

GENERAL SOIL MAP
UPPER SANTA ANA RIVER BASIN CALIFORNIA
— LEGEND —
Soils on recent, well-drained valley-fill
Soils on somewhat poorly to poorly drained valley-fill
Soils on old valley-fill
Soils on upland areas
MILES
Soil association data furnished by the Soil Conservation Service, USDA
SOIL ASSOCIATIONS
AD-bb Arlington-Buren association, 2-9 percent slopes
An-Dl-D Altamont-Diablo association, 9-30 percent slopes
An-Ge-SZ Altamont-Gaviota-Soper association, 15-50 percent slopes
Az-Pn Arbuckle-Perkins association, 2-9 percent slopes
BZ-sF Badland-San Timoteo association, 15-50 percent slopes, eroded
Cc-Li Cajalco-Los Posas association, 5-15 percent slopes
Cc-Th Cajalco-Temescal rocky association, 9-50 percent slopes
CE Chino association, 0-2 percent slopes
CK-Fa Cieneba-Fallbrook association, 2-75 percent slopes
cn-SE Crafton-Sheephead association, 15-50 percent slopes
CR Cropley association, 0-2 percent slopes
Dg-Pa-Hq Delhi-Pachappa-Hilmar association, 0-15 percent slopes
Dt-Wk-CE Domino-Willows-Chino association, 0-5 percent slopes
Fa-Vt-D Fallbrook-Vista association, 2-15 percent slopes
Fa-Vt-F Fallbrook-Vista association, rocky 15-50 percent slopes, eroded
Fp-Gw Foster-Grangeville association, 0-2 percent slopes
Fw-Em Friant-Escondido association, rocky, 30-75 percent slopes, eroded
Fw-Em-Vc Friant, rocky, -Escondido, rocky, -Vallecitos variant association, 2-50 percent slopes, eroded
Fw-LB-Em Friant, rocky-Lodo, rocky-Escondido, 2-50 percent slopes, eroded
GH-cl Garretson-Cortina association, 2-9 percent slopes
Gw-Di Grangeville-Dello association, 0-5 percent slopes
Hd Hanford association, 2-5 percent slopes
Hd-Gx Hanford-Greenfield association, 0-2 percent slopes
Hd-Gx-C Hanford-Greenfield-Ramona association, 2-9 percent slopes
SOIL ASSOCIATIONS - cont.
MB-CE Merrill-Chino association, 0-2 percent slopes
mo-Ex Monserate-Exeter association, 0-9 percent slopes
mo-Mb Monserate-Madera association, 2-9 percent slopes
Ob-Ch Oak Glen-Calpine association, 5-15 percent slopes
Py Placentia association, 2-9 percent slopes
RB Rough broken land
Rb-Rc Rough broken land-Ramona association, 9-50 percent slopes
Rb-TY Rough broken land-Terrace Escarpment
Rc-Ad Ramona-Arlington association, 5-15 percent slopes, eroded
Rc-Gx Ramona-Greenfield association, 2-5 percent slopes
RL Rock land
Rn-Zm Rincon-Zamora association, 2-9 percent slopes
RW Riverwash
Se-Sf-F San Andreas-San Benito association, 30-70 percent slopes, eroded
Sf-SZ San Benito-Soper association, 30-50 percent slopes
Sh-MC San Emigdio-Metz association, 0-5 percent slopes
TO-Dg Tujunga-Delhi association, 0-2 percent slopes, eroded
TO-Gx-Hd Tujunga-Greenfield-Hanford association, 0-9 percent slope, eroded
TD-SV Tujunga-Soboba association, 0-5 percent slopes
Tp-Ep Tivy-Exchequer association, rocky, 30-75 percent slopes, eroded
Tx-Bp-Wd Traver-Buchenau-Waukena association, 0-5 percent slopes
Vt-CK Vista-Cieneba association, rocky, 15-50 percent slopes, eroded
Yk-Hu-Wr Yokohl-Honcut-Wyman association, 2-15 percent slopes
SAN GABRIEL MOUNTAINS
SAN BERNARDINO MTS
SANTA ANA MOUNTAINS
SANTA ANA RIVER
Big Bear Lake
Lake Mathews
Irvine Lake
Prado Flood Control Basin
LIMIT OF STUDY AREA
WATERSHED BOUNDARY



DENITRIFICATION POTENTIAL OF SOILS
UPPER SANTA ANA RIVER BASIN CALIFORNIA
— LEGEND —
LOW
MODERATE
0 5
MILES
Soil association data furnished by the Soil Conservation Service, USDA
R. 9 W.
R. 8 W.
R. 7 W.
R. 6 W.
R. 5 W.
R. 4 W.
R. 3 W.
R. 2 W.
R. 1 W.
R. 1 E.
R. 2 E.
T. 3 N.
T. 2 N.
T. 1 N.
T. 1 S.
T. 2 S.
T. 3 S.
T. 4 S.
T. 5 S.
34° 15'
34° 00'
117° 45'
117° 30'
117° 15'
117° 00'
116° 45'
SAN GABRIEL MOUNTAINS
SAN BERNARDINO MTS
SANTA ANA MOUNTAINS
WATERSHED BOUNDARY
LIMIT OF STUDY AREA
SANTA ANA RIVER
Big Bear Lake
Baldwin Lake
Lake Mathews
Prado Flood Control Basin
SAN BERNARDINO
RIVERSIDE
REDLANDS
POMONA
ONTARIO
UPLAND
CLAREMONT
FONTANA
RIALTO
COLTON
LOMA LINDA
MENTONE
YUCAIPA
BEAUMONT
CHINO
CORONA
ARLINGTON
YORBA LINDA
ORANGE
SANTA ANA
Irvine Lake
L. A. CO.
ORANGE CO.
LOS ANGELES COUNTY
SAN BERNARDINO COUNTY
SAN BERNARDINO COUNTY
RIVERSIDE COUNTY
RIVERSIDE COUNTY
ORANGE COUNTY
SOIL ASSOCIATIONS
AD - bb Arlington - Buren association, 2 - 9 percent slopes
An - Dl - D Altamont - Oiablo association, 9 - 30 percent slopes
An - Ge - SZ Altamont - Goviota - Soper association, 15 - 50 percent slopes
Az - Pn Arbuckle - Perkins association, 2 - 9 percent slopes
BZ - sF Badland - San Timoteo association, 15 - 50 percent slopes, eroded
Cc - Li Cajolco - Los Posas association, 5 - 15 percent slopes
Cc - Th Cajolco - Temescol rocky association, 9 - 5D percent slopes
CE Chino association, D - 2 percent slopes
CK - Fo Cieneba - Follbrook association, 2 - 75 percent slopes
cn - SE Crofton - Sheephead association, 15 - 5D percent slopes
CR Cropley association, 0 - 2 percent slopes
Og - Pa - Hq Delhi - Pachappo - Hilmar association, 0 - 15 percent slopes
Dt - Wk - CE Domino - Willows - Chino association, 0 - 5 percent slopes
Fa - Vt - O Follbrook - Vista association, 2 - 15 percent slopes
Fa - Vt - F Follbrook - Vista association, rocky 15 - 50 percent slopes, eroded
Fp - Gw Foster - Grangeville association, 0 - 2 percent slopes
Fw - Em Friont - Escondido association, rocky, 30 - 75 percent slopes, eroded
Fw - Em - Vc Friant, rocky, - Escondido, rocky, - Vollecitos variant association, 2 - 50 percent slopes, eroded
Fw - LB - Em Friont, rocky - Lodo, rocky - Escondido, 2 - 5D percent slopes, eroded
GH - cl Garretson - Cortina association, 2 - 9 percent slopes
Gw - Oi Grangeville - Dello association, 0 - 5 percent slopes
Hd Hanford association, 2 - 5 percent slopes
Hd - Gx Hanford - Greenfield association, 0 - 2 percent slopes
Hd - Gx - C Hanford - Greenfield - Ramona association, 2 - 9 percent slopes
SOIL ASSOCIATIONS - cont.
MB - CE Merrill - Chino association, 0 - 2 percent slopes
mo - Ex Monserate - Exeter association, 0 - 9 percent slopes
mo - Mb Monserate - Modera association, 2 - 9 percent slopes
Ob - Ch Ook Glen - Calpine association, 5 - 15 percent slopes
Py Placentia association, 2 - 9 percent slopes
RB Rough broken land
Rb - Rc Rough broken land - Ramona association, 9 - 50 percent slopes
Rb - TY Rough broken lond - Terrace Escarpment
Rc - Ad Ramona - Arlington association, 5 - 15 percent slopes, eroded
Rc - Gx Romona - Greenfield association, 2 - 5 percent slopes
RL Rock land
Rn - Zm Rincon - Zomora association, 2 - 9 percent slopes
RW Riverwash
Se - Sf - F San Andreas - San Benito assaciation, 30 - 70 percent slopes, eroded
Sf - SZ San Benito - Soper assaciation, 30 - 50 percent slopes
Sh - MC San Emigdio - Metz association, 0 - 5 percent slopes
TO - Og Tujunga - Oelhi association, 0 - 2 percent slopes, eroded
TD - Gx - Hd Tujunga - Greenfield - Hanford association, 0 - 9 percent slope, eroded
TD - SV Tujungo - Sobobo association, D - 5 percent slopes
Tp - Ep Tivy - Exchequer association, rocky, 30 - 75 percent slopes, eroded
Tx - Bp - Wd Traver - Buchenau - Waukeno association, 0 - 5 percent slopes
Vt - CK Vista - Cieneba association, rocky, 15 - 50 percent slopes, eroded
Yk - Hu - Wr Yokohl - Honcut - Wyman association, 2 - 15 percent slopes



UPPER SANTA ANA RIVER BASIN CALIFORNIA
WATER TRANSMISSION CLASSES
HIGH
Nearly level, 0-5 percent slopes
Sloping, >5 percent slopes
MODERATE
Nearly level
Sloping
LOW
Nearly level, permeable substratum
Sloping, permeable substratum
Sloping, dense substratum or rock
VERY LOW
Sloping, permeable substratum
Sloping, dense substratum or rock
0 5 MILES
Soil association data furnished by the Soil Conservation Service, USDA
SOIL ASSOCIATIONS
AD - bb Arlington - Buren association, 2 - 9 percent slopes
An - Dl - D Altamont - Diablo association, 9 - 30 percent slopes
An - Ge - SZ Altamont - Gaviota - Soper association, 15 - 50 percent slopes
Az - Pn Arbuckle - Perkins association, 2 - 9 percent slopes
BZ - sF Badland - San Timoteo association, 15 - 50 percent slopes, eroded
Cc - Li Cajalco - Las Posas association, 5 - 15 percent slopes
Cc - Th Cajalco - Temescal rocky association, 9 - 50 percent slopes
CE Chino association, 0 - 2 percent slopes
CK - Fa Cieneba - Fallbrook association, 2 - 75 percent slopes
cn - SE Crafton - Sheephead association, 15 - 50 percent slopes
CR Cropley association, 0 - 2 percent slopes
Dg - Pa - Hq Delhi - Pachappa - Hilmar association, 0 - 15 percent slopes
Dt - Wk - CE Domino - Willows - Chino association, 0 - 5 percent slopes
Fa - Vt - O Fallbrook - Vista association, 2 - 15 percent slopes
Fo - Vt - F Fallbrook - Vista association, rocky 15 - 50 percent slopes, eroded
Fp - Gw Foster - Grangeville association, 0 - 2 percent slopes
Fw - Em Friant - Escondido association, rocky, 30 - 75 percent slopes, eroded
Fw - Em - Vc Friant, rocky, - Escondido, rocky, - Vallecitos variant association, 2 - 50 percent slopes, eroded
Fw - LB - Em Friant, rocky - Lodo, rocky - Escondido, 2 - 50 percent slopes, eroded
GH - cl Garretson - Cortina association, 2 - 9 percent slopes
Gw - Oi Grangeville - Oello association, 0 - 5 percent slopes
Hd Hanford association, 2 - 5 percent slopes
Hd - Gx Hanford - Greenfield association, 0 - 2 percent slopes
Hd - Gx - C Hanford - Greenfield - Ramona association, 2 - 9 percent slopes
SOIL ASSOCIATIONS - cont.
MB - CE Merrill - Chino association, 0 - 2 percent slopes
mo - Ex Monserate - Exeter association, 0 - 9 percent slopes
mo - Mb Monserate - Madero association, 2 - 9 percent slopes
Ob - Ch Oak Glen - Calpine association, 5 - 15 percent slopes
Py Placentia association, 2 - 9 percent slopes
RB Rough broken land
Rb - Rc Rough broken land - Ramona association, 9 - 50 percent slopes
Rb - TY Rough broken land - Terrace Escarpment
Rc - Ad Ramona - Arlington association, 5 - 15 percent slopes, eroded
Rc - Gx Ramona - Greenfield association, 2 - 5 percent slopes
RL Rock land
Rn - Zm Rincon - Zamora association, 2 - 9 percent slopes
RW Riverwash
Se - Sf - F San Andreas - San Benito association, 30 - 70 percent slopes, eroded
Sf - SZ San Benito - Soper association, 30 - 50 percent slopes
Sh - MC San Emigdio - Metz association, 0 - 5 percent slopes
TO - Dg Tujunga - Delhi association, 0 - 2 percent slopes, eroded
TD - Gx - Hd Tujunga - Greenfield - Hanford association, 0 - 9 percent slope, eroded
TD - SV Tujunga - Soboba association, 0 - 5 percent slopes
Tp - Ep Tivy - Exchequer association, rocky, 30 - 75 percent slopes, eroded
Tx - Bp - Wd Traver - Buchenau - Waukena association, 0 - 5 percent slopes
Vt - CK Vista - Cieneba association, rocky, 15 - 50 percent slopes, eroded
Yk - Hu - Wr Yokohl - Honcut - Wyman association, 2 - 15 percent slopes